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ALTERNATIVE THEATER OF OPERATIONS BUILDING SYSTEMS.(U)
JUL 77 A M KAO, J COOK

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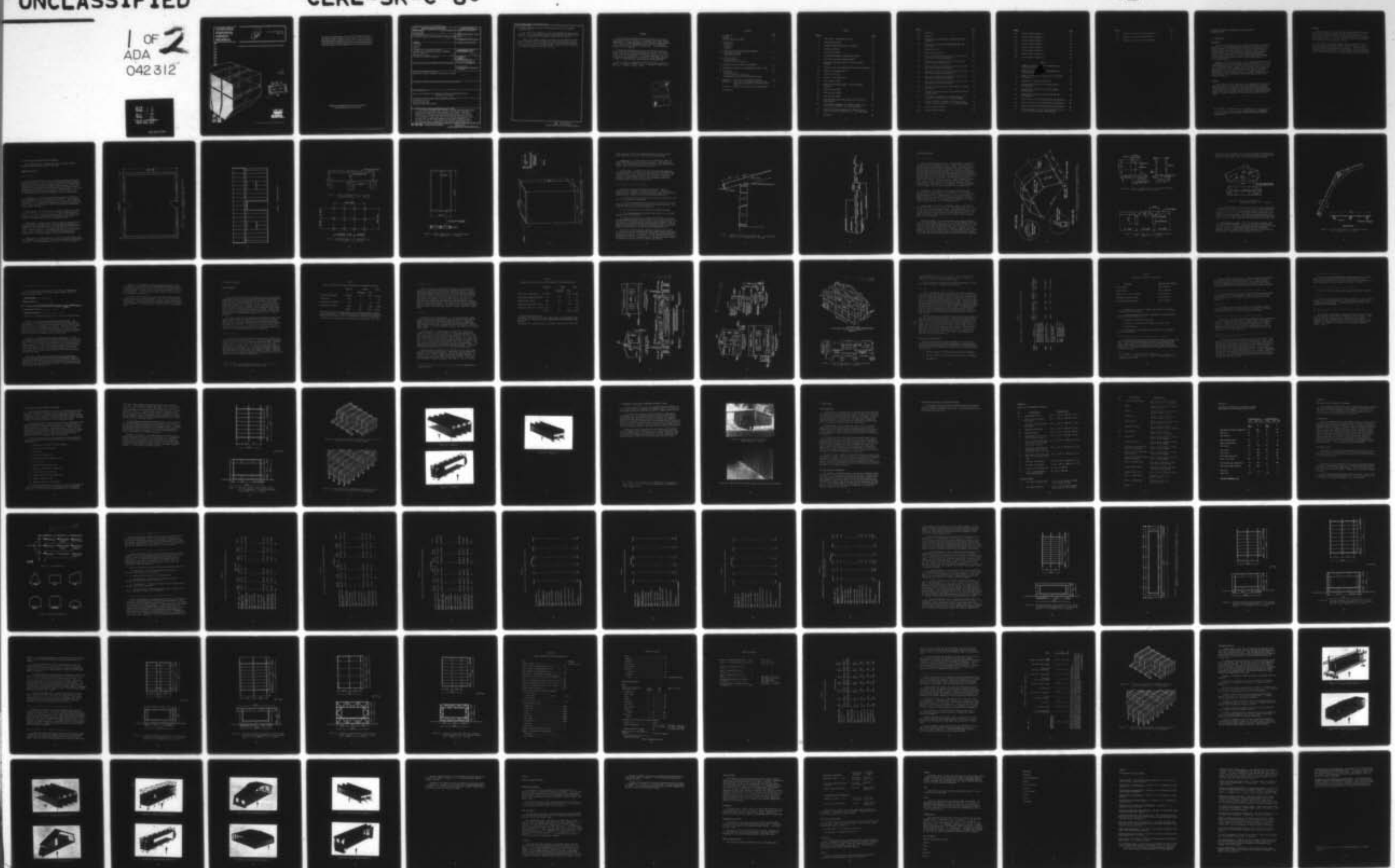

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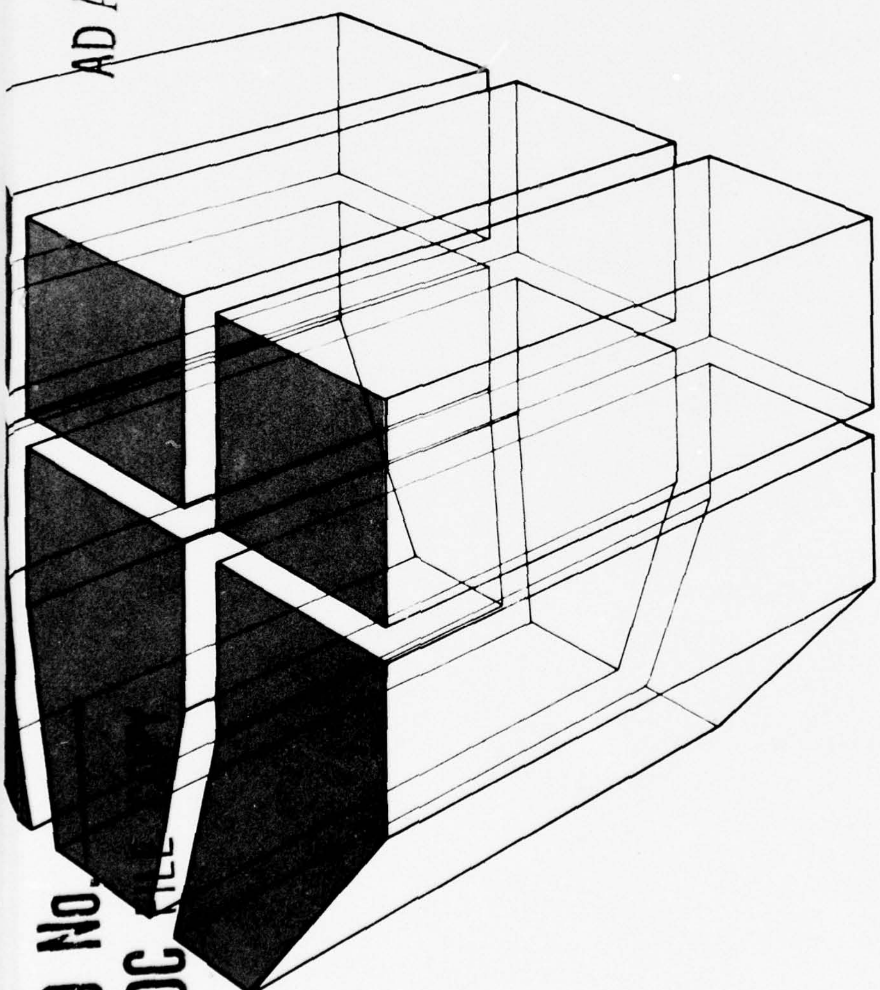
July 1977

ALTERNATIVE THEATER OF OPERATIONS BUILDING SYSTEMS



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This report documents the findings resulting from fabricating and erecting two prototype building systems--a fiberglass-reinforced paperboard building and a pipe-frame building system. The results indicate that the pipe-frame building concept has potential for use in the theater of operations (TO) if the required construction skills and materials are made more compatible with those expected to be available in the TO. The fiberglass-reinforced paperboard building has not weathered satisfactorily. The costs of both systems are

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reasonable compared to those of selected Army Facilities Components System facilities.

This report also summarizes a study on development of new building concepts. It is believed that several of the concepts developed in the study can be developed into effective systems for use in a TO.

Finally, this report presents the results of a performance inspection of an experimental foam/wood panelized building during its first year in service. The results indicate that the building has weathered satisfactorily except for rainwater seepage along the joints, which can be prevented by caulking along the joints.

FOREWORD

This study was performed for the Directorate of Facilities Engineering, Office of the Chief of Engineers (OCE), under Project 4A763734DT07, "Military Construction and Field Engineering Development"; Task 06, "Base Development"; Work Unit 002, "Expedient Structural Systems for Theater of Operations." The OCE Technical Monitor is Mr. E. McWhite.

The work was performed by the Military and Base Engineering Branch (FOM) of the Facility Operations Division (FO), U.S. Army Construction Engineering Research Laboratory (CERL). Dr. A. M. Kao is the Principal Investigator. The concept development study was conducted by the Department of Architecture at the University of Illinois at Urbana-Champaign under contract DACA88-76-M-0258.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director. Mr. R. B. Blackmon is Chief of FO, and Dr. E. L. Marvin is Chief of FOM.

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1 INTRODUCTION

Background

The Corps of Engineers (CE) has recognized the need for new and improved construction techniques and materials to support the Army in future theaters of operations (TO) by placing increased emphasis on developing more timely and responsive construction support efforts for new and revised tactical scenarios. Research and development efforts in this area at the U.S. Army Construction Engineering Research Laboratory (CERL) have been directed toward the development of structural systems capable of meeting large percentages of TO facility requirements.

During FY 74, FY 75, and part of FY 76, CERL developed and refined a complementary foam/wood structural system suitable for TO use. Two field demonstrations of this system have been carried out: one at the U.S. Army Engineer School (USAES),[1] and the other at Fort Rucker, AL. These buildings will be inspected annually to evaluate the system's performance. During the latter part of FY 76, work was done to develop and conduct prototype testing of additional building systems and to develop several additional feasible building concepts for possible future use.

Purpose

The purposes of this report are (1) to document the findings and conclusions resulting from fabricating and erecting two prototype building systems -- a fiberglass-reinforced paperboard building and a pipe-frame building system; (2) to summarize the study performed to develop feasible new building concepts; and (3) to present the results of the first annual inspection of the foam/wood building erected at USAES.

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[1] R. L. Trent, T. M. Whiteside, and J. Robertus, *Field Experiment on a Prefabricated Foam/Wood Structure*, Interim Report C-50/ADA032726 (U.S. Army Construction Engineering Research Laboratory [CERL], October 1976).

Approach

The field test of the two building systems involved fabricating the building components at CERL and erecting the buildings. The results were evaluated by comparing labor and material costs of the experimental systems with those of standard Army Facilities Component System (AFCS designs). The field test results were also evaluated using previously developed design criteria.

The building concept development study was conducted in two phases by students and faculty members in the University of Illinois at Urbana-Champaign Department of Architecture. The first phase, which followed a structured approach, started at a general level and proceeded toward the specific. The second phase solicited building system ideas from architectural students through a design competition.

2 SYSTEM DESCRIPTION AND ERECTION PROCEDURES

This chapter desribes the paperboard and pipe-frame building systems and the procedures used to erect them.

Paperboard Structure

System Description

The paperboard building system is a panelized system which can be erected on a concrete slab or a raised wood foundation which provides flooring and acts as an anchoring base. Figures 1 and 2 show the plan and elevation of the raised wood foundation building used in the test. The building superstructure was purchased from the developer, Vertas International, for $2500. The system, which required 130 cu ft (3.7 m^3) of shipping space, was packed and shipped to CERL in a truck. The following paragraphs describe the components of the building system.

Foundation. The raised wood foundation system was selected for this experiment based on site conditions and economy. The foundation was constructed of structural bents with 2 in. x 6 in. (55 m x 152 mm) lumber posts set in augered holes embedded with concrete (Figures 3 and 4). The bents were fabricated at CERL in accordance with the design drawing shown in Figure 3.

Floor System. The floor system is composed of panels constructed of 4 ft x 8 ft x 1/2 in. (1.2 m x 2.4 m x 13 mm) plywood sheets and 2 in. x 4 in. (51 mm x 102 mm) dimensional lumber. These panels were fabricated at CERL in accordance with the design drawing shown in Figure 5. They were then nailed to the foundation bents.

Wall System. The wall panels, which are made of corrugated fiberboard coated with fiberglass on one side and along the edges, were shipped flat from the manufacturer in an unfolded configuration (30 in. x 102 in. [0.8 m x 2.6 m]). They were folded into 7 in. x 16 in. x 88 in. (178 mm x 406 mm x 2.2 m) standard wall modules at the building site, as shown in Figure 6. The flat panels were scored by the manufacturer to facilitate bending in the prescribed directions.

Roof System. The roof panels are similar to the wall panels, but have different size and scoring. They were also shipped flat and folded at the site. The roof panels bear on 2 in.x 8 in. (51 mm x 203 mm)

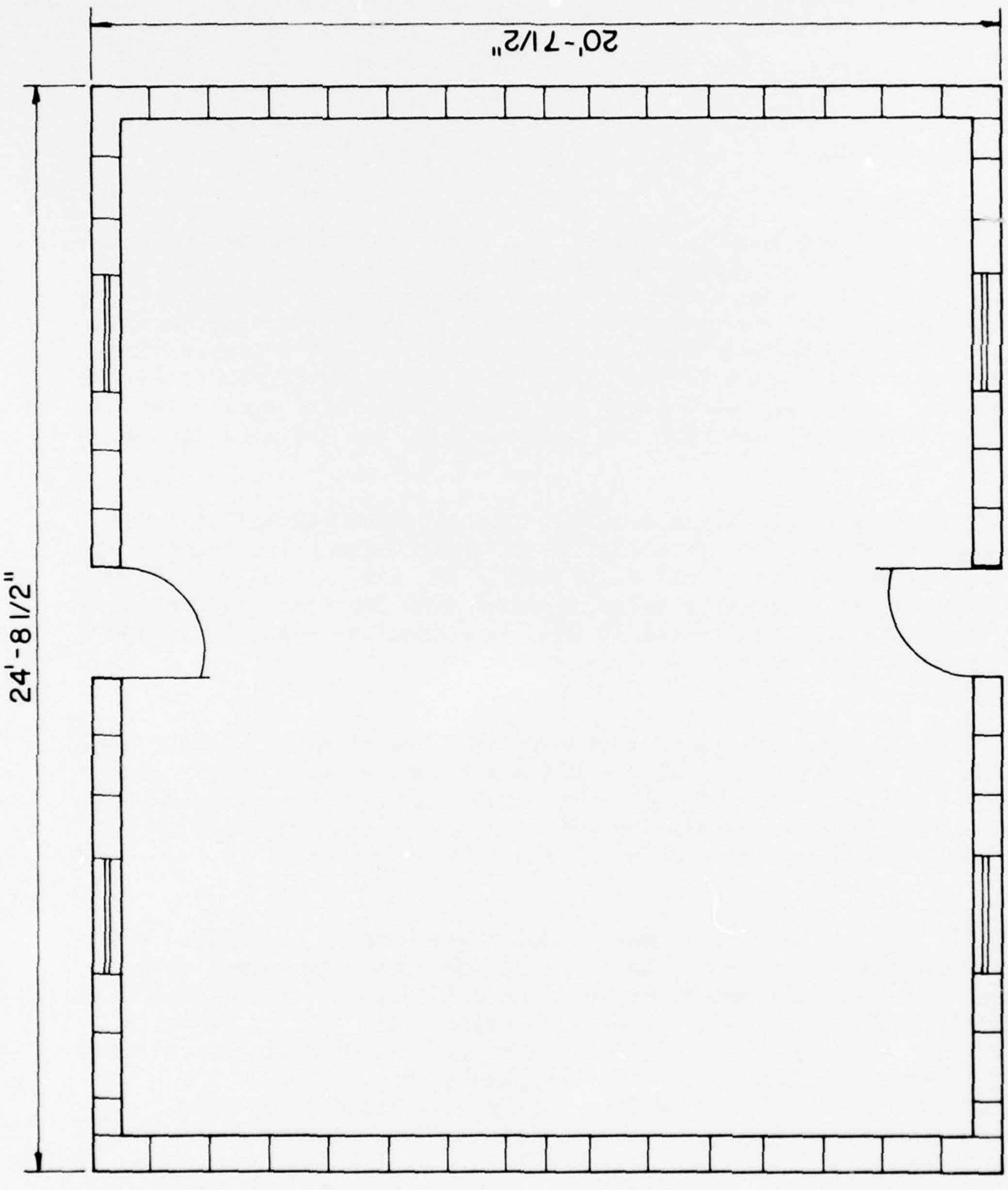

Figure 1. Floor plan -- paperboard building. SI conversion factor: 1 ft = 0.3048; 1 in. = 25.4 mm.

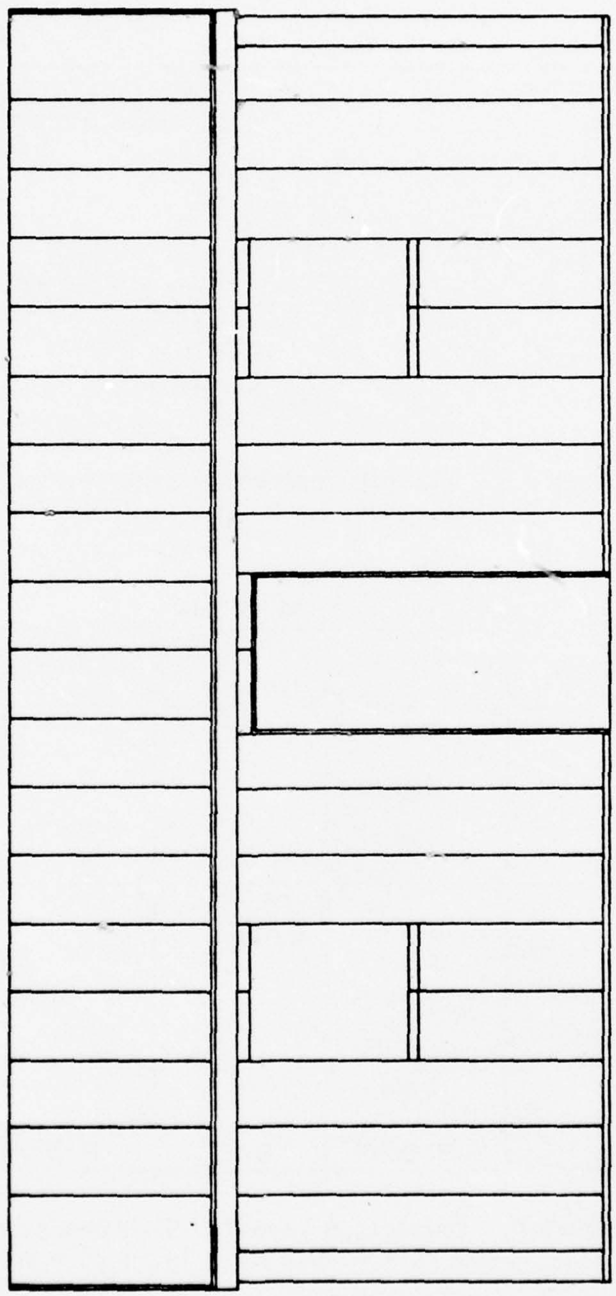

Figure 2. Paperboard building.

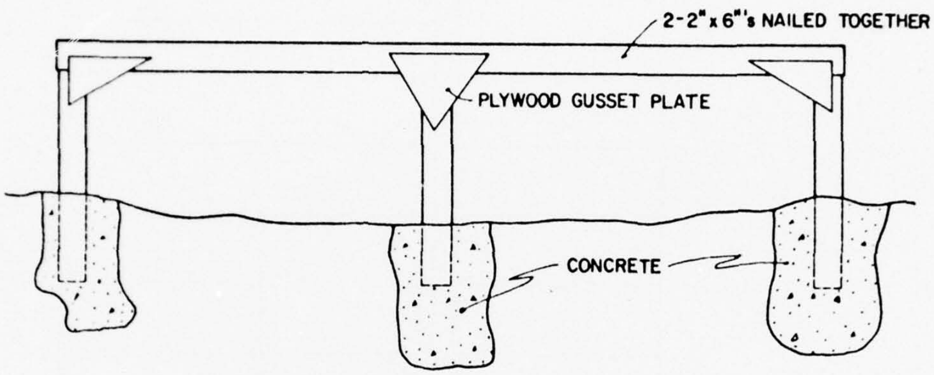

Figure 3. Example foundation bent set in concrete. SI conversion factor: 1 in. = 25.4 mm.

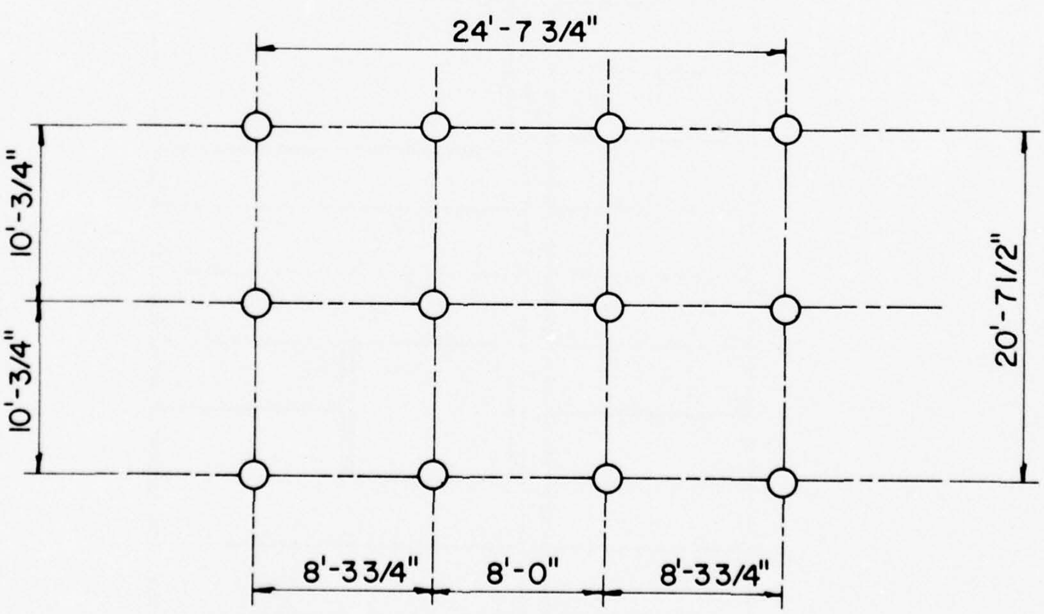

Figure 4. Foundation layout. SI conversion factor: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

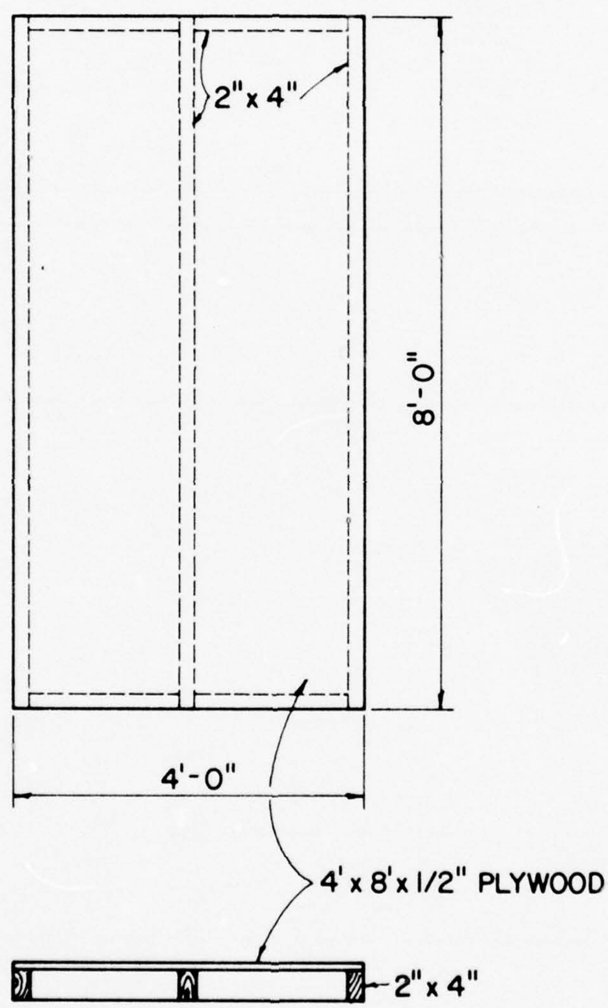

Figure 5. Typical floor panel. SI conversion factor:
1 ft = 0.3048 m; 1 in. = 25.4 mm.

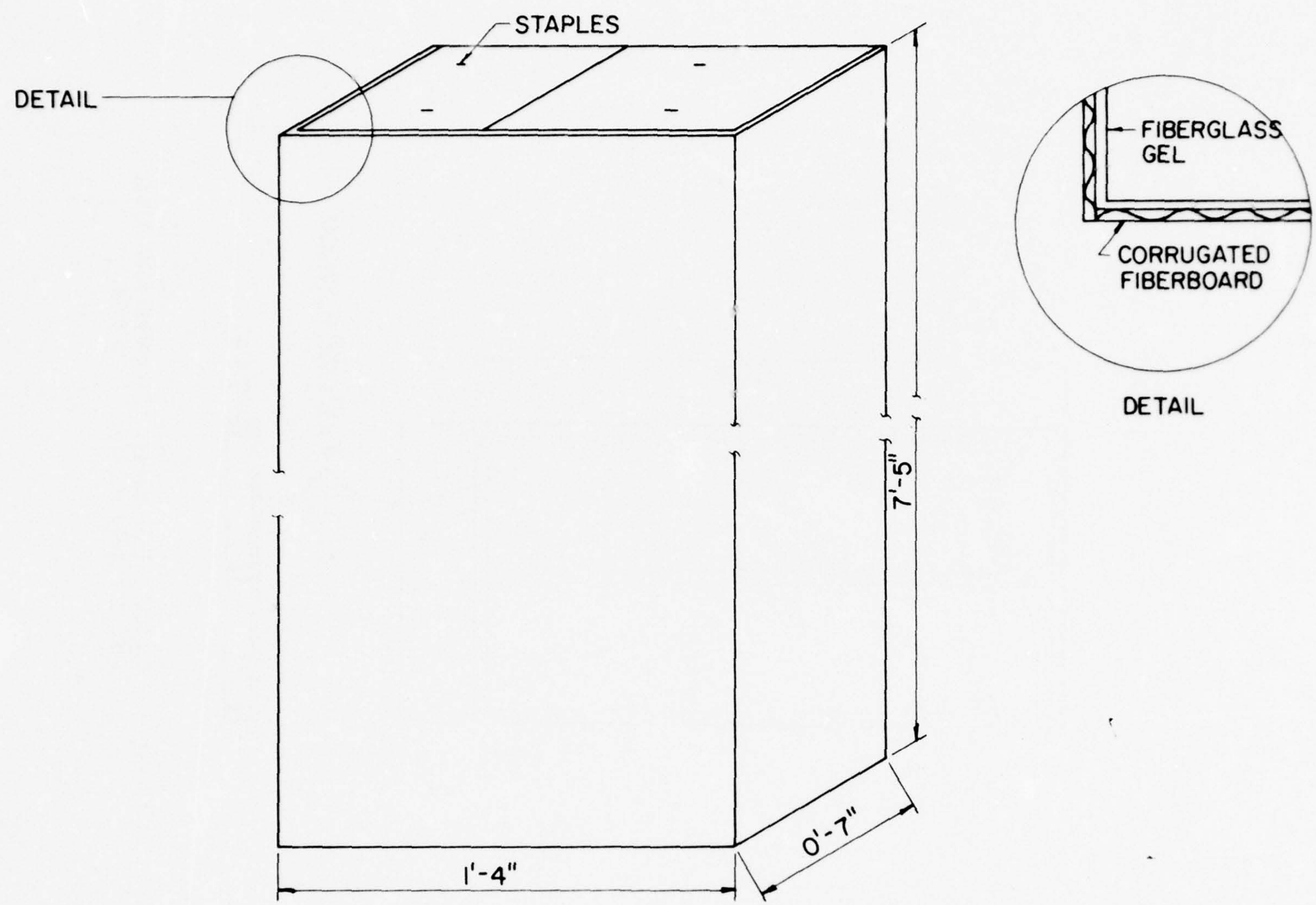

Figure 6. Corrugated paperboard standard wall module. SI conversion factor: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

lumber secured on top of the paperboard walls (Figure 7) and on a roof ridge beam. No truss is used for the roofing system.

Lumber Parts. The building relies on dimensional lumber for some of the structural and connection solutions. Such lumber was used at the top and bottom of the wall panels, between wall and roof panels, under the eaves, along the fascia, etc.

Miscellaneous. In addition to the above-described components, two doors and four aluminum single-hung windows were included in the tested building system. Fiberglass fabric and gel were provided for sealing the joints between the wall and roof panels. Appendix A includes a complete parts list of all the components except the fiberglass fabric tape and fiberglass gel.

Field Experiment Erection Procedures

The building system was erected in two phases: Phase I -- fabrication and placement of foundation; Phase II -- erection of superstructure. Sequences for each activity are shown in an activity network diagram (Figure 8) and are briefly described below:

1. The building site was laid out and the exact locations of the holes to be augered were determined.

2. Holes were augered and the foundation legs were set in place. Foundation bents were aligned and fixed in the proper locations. Concrete was then placed to set the foundation.

3. The floor panels were installed on the foundation bents.

4. The superstructure (wall panels, roof panels, etc.) was then erected on the finished floor.

The foundation and floor were completed well before the receipt of the paperboard building superstructure. Had the superstructure been available, the paperboard building could have been erected as soon as the concrete was poured and the floor panels were installed, since the platform was supported or shimmed with a temporary cradle. This procedure eliminates waiting for the concrete foundation to cure.

A total of 191 man-hours was required to complete the building. It should be noted that unskilled part-time student laborers were used to erect the structure. In addition, the work was done intermittently, thus reducing construction efficiency. If the construction could be performed by troops on a continuous basis, the total man-hours required to complete the building could be reduced considerably.

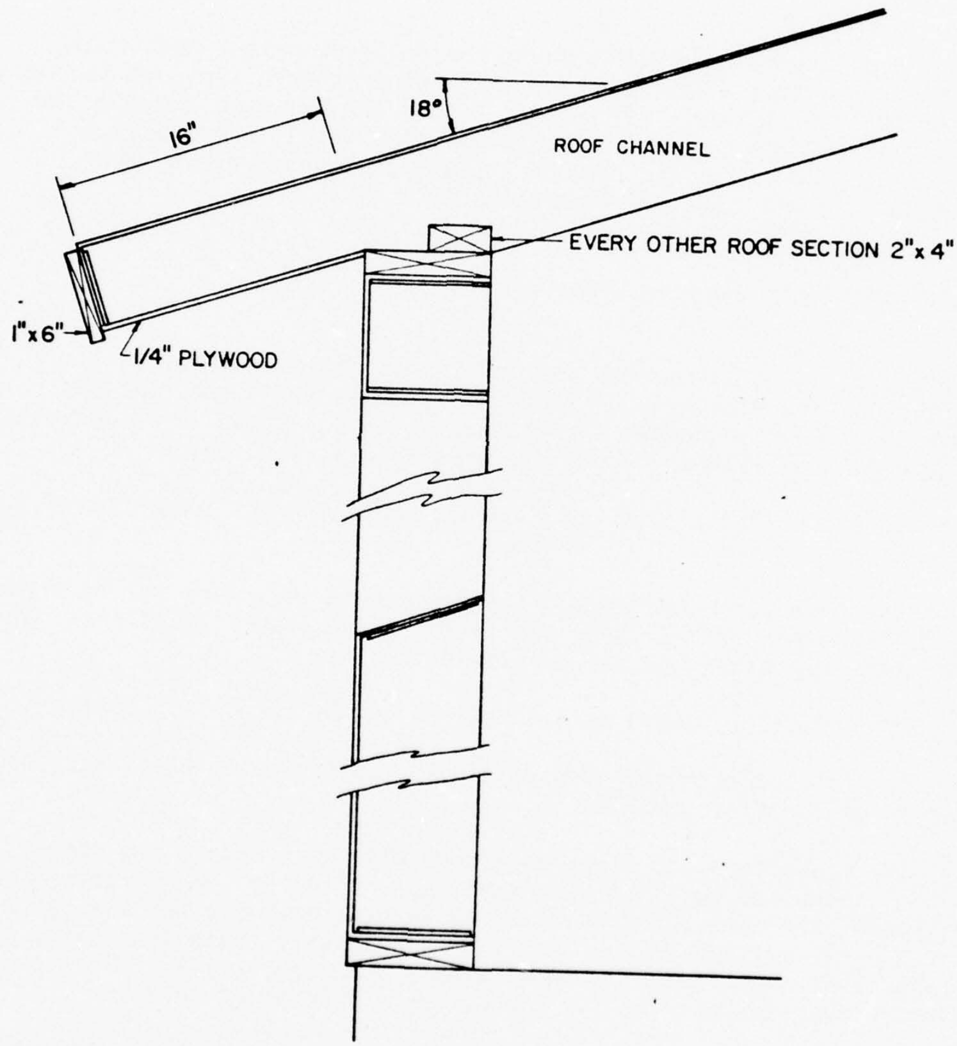

Figure 7. Roof panel resting on paperboard wall. SI conversion factor: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

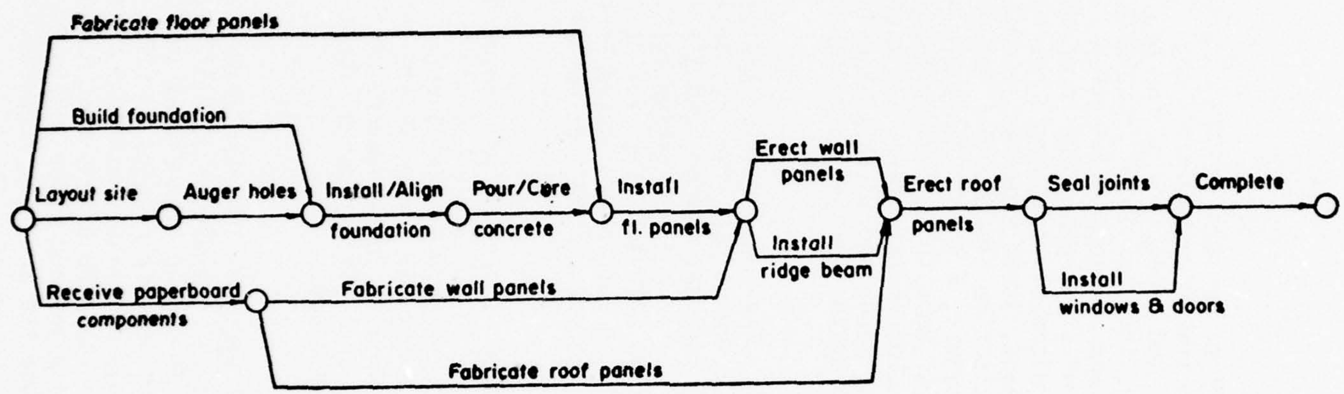

Figure 8. Paperboard building system -- activity network diagram.

Pipe-Frame Building

System Description

The pipe-frame building system is a componentized system which is erected on a special foundation system. Figure 9 shows the basic characteristics and dimensions of the building. The building system can be separated into two major components: the basic structural framing system and the enclosure system. The structural frame can be constructed of steel pipe, aluminum pipe, polyvinyl chloride (PVC) pipe, or other materials that meet the required structural properties. In this experiment, steel pipe was selected because of its availability and the project's time limitation. The enclosure system can be fabricated of canvas, 4 ft x 8 ft (1.2 m x 2.4 m) plywood sheets and 2 in. x 4 in. (51 mm x 102 mm) dimensional lumber, sheet metal, or other feasible closure material. Two types of enclosure material, wood and canvas, were used in this experiment. The major components of the building system for this experiment are described below.

Foundation. The foundation of the pipe-frame building was specially fabricated at CERL for this building. It consisted of a base plate, two vertical plates, and a 4 ft 6 in. (1.4 m) steel pipe welded together to form a foundation post. Each of the vertical plates was drilled with two holes for bolting purposes. The steel foundation post was set in an augered hole and embedded with concrete. Figure 10 shows the detail of the foundation posts.

Floor System. The floor was composed of panels constructed of 4 ft x 8 ft x 1/2 in. (1.2 m x 2.4 m x 13 mm) plywood and 2 in. x 4 in. (51 mm x 102 mm) dimensional lumber. The panels were set on 2 in. x 6 in. (51 mm x 152 mm) lumber joists supported with two wooden posts at the middle and with joist hangers at the ends (Figure 11). It should be noted that other types of floor systems, such as concrete slab, can also be used.

Pipe-Frame System. The pipe frames were fabricated by jointing 7 ft 7 in. (2.3 m) long pieces of 2 1/2 in. (64 mm) diameter steep pipe together with 135-degree pipe elbows to form a frame (Figure 12). The pipes and elbows were fabricated at CERL. High-strength steel bolts (3/4 in. [19 mm]) dia.) were used for fasteners. Originally, it was planned to have the pipe elbows cast so that they would provide a tight fit between the pipes and elbow joints to eliminate bolting at these joints and reduce the accuracy required in fabricating these components.

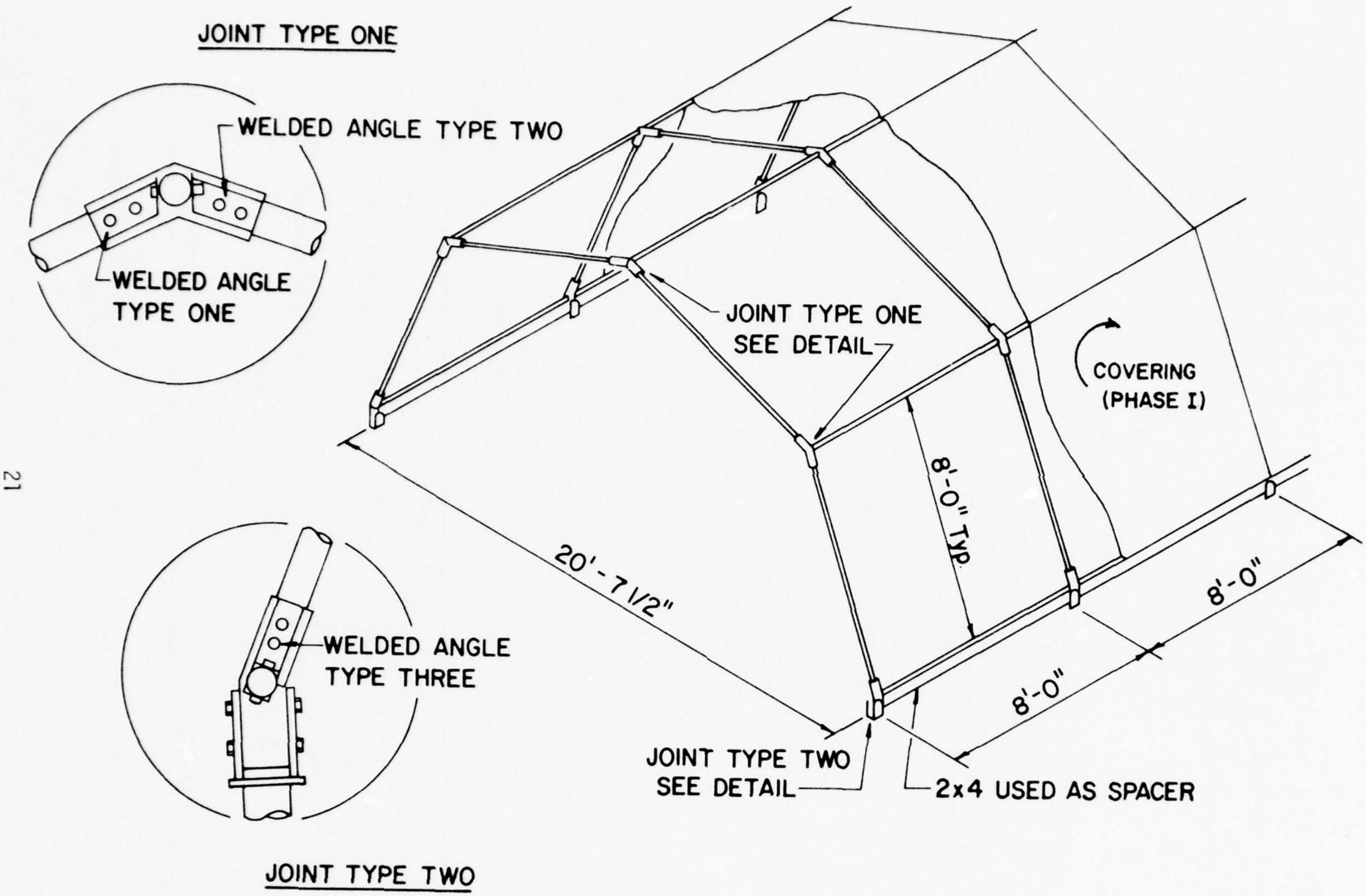

Figure 9. Characteristics and dimensions of pipe-frame building.
SI conversion factors: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

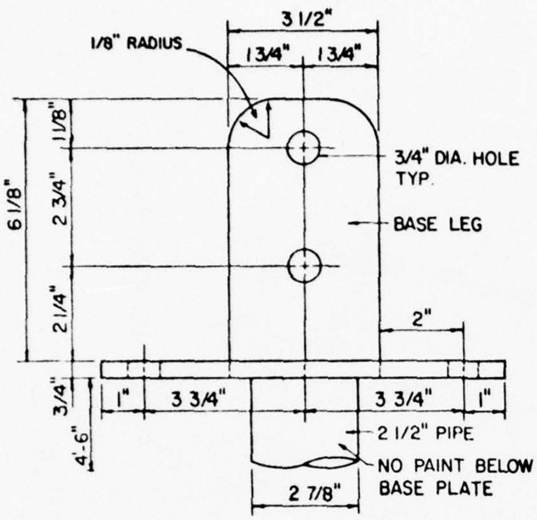

Figure 10. Details of foundation post. SI conversion factors: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

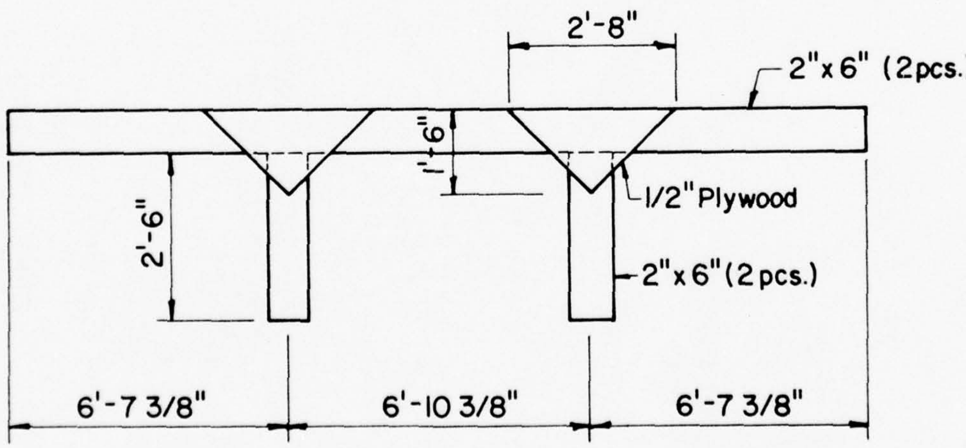

Figure 11. Typical floor joist. SI conversion factors: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

Because of time and economy, this plan was abandoned, and welded pipe joints were used instead. Use of welded pipe joints should not affect the overall evaluation of the erection of this building system.

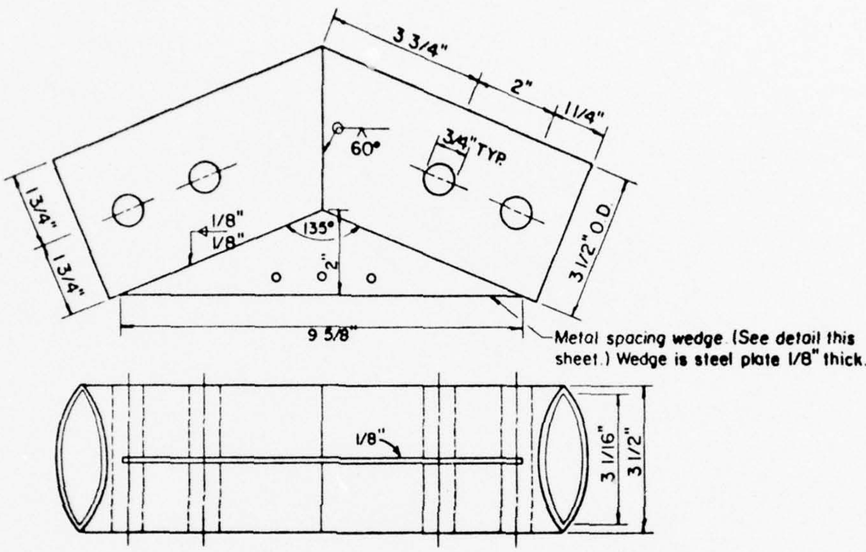

Figure 12. Detail of pipe elbow joist.
SI conversion factor: 1 in. = 25.4 mm.

Wall and Roof System. The walls and roof were a panelized system composed of 4 ft x 8 ft x 1/2 in. (1.2 m x 2.4 m x 13 mm) plywood and 2 in. x 4 in. (51 mm x 102 mm) dimensional lumber (Figure 13). The ends of the 2 in. x 4 in. (51 mm x 102 mm) lumber were notched to fit between the supporting pipes. The panels were prefabricated on the ground, set on the frame, and connected and fastened with gusset plates under the pipes to form a monolithic enclosure system (wall and roof).

Canvas Enclosure System. This is an alternate enclosure system for the pipe-frame structure. The canvas was made of weatherproof, flame-resistant, fabric-laminated fiberglass material weighing 17.5 oz/sq ft (5.3 kg/m^2). Future investigations should include those membranes available through the existing Army supply system, such as polyethylene, lightweight airfield membrane (T-17), etc.

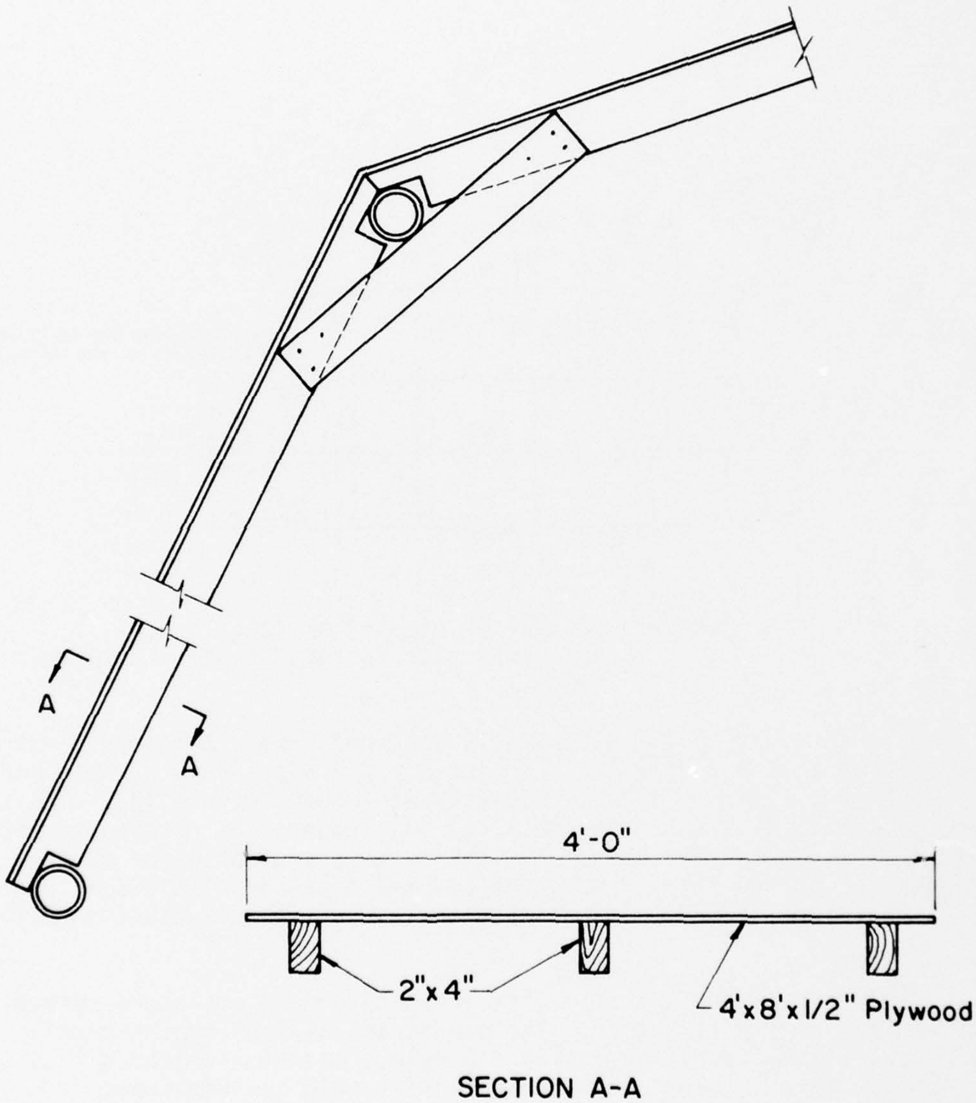

Figure 13. Wall and roof panels. SI conversion factors: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

Field Experiment Erection Procedures

The building system was erected in four phases. Sequences for each activity are shown in an activity network diagram (Figure 14) and are described below.

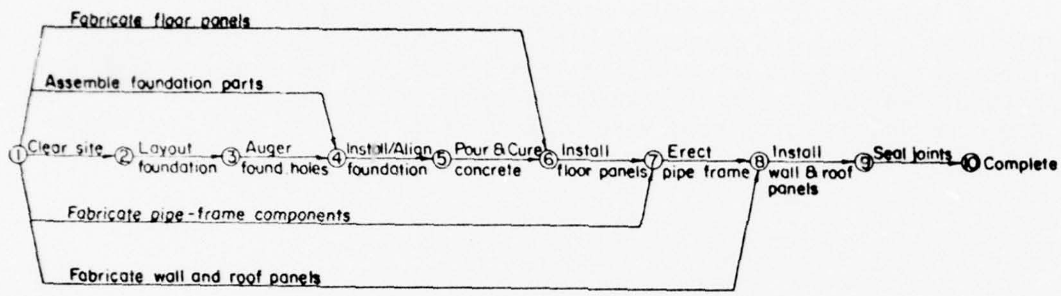

Figure 14. Pipe-frame building system -- activity network diagram.

Phase I -- Fabrication of Foundation and Floor System. The building was laid out and the locations for the holes to be augered were determined. The holes were then augered and the foundation posts were set in place and embedded with concrete. The floor joist hangers were attached to the foundation posts and the joists were set and nailed into place. Next, holes around the posts at interior supports were filled with gravel and dirt. The prefabricated floor panels were then placed and nailed securely onto the floor joists.

Phase II -- Erection of the Structural Pipe Frame. The pipe-frame members were assembled on the ground, and the ends were attached to the foundation posts with one bolt each to form hinges at the supports. The first frame was then rotated into position and braced with temporary supports. The rest of the frames were assembled similarly on the ground one at a time, rotated into position, and connected to the already erected frames. The erection procedures were fairly simple and quick; four men took an average of 30 minutes to assemble and erect one frame.

Phase III -- Placing the Prefabricated Wall and Roof Panels. After all the panels were placed, they were connected and fastened securely with the gusset plates under the pipes to form a monolithic enclosure system. End panels were then attached and nailed into place. When the canvas was to be used for enclosure, it was merely laid over the frame and tied securely to it.

Phase IV -- Installation of Metal Ridge Cap and Sealing Joints. This phase was required only for the plywood panel enclosure system. Joints between wall and roof panels were sealed with caulking compound and batten boards. Roofing felt was not used to cover the roof in this experiment. To insure complete water tightness, the roof should be covered with roofing felt.

A total of 222 man-hours was required to complete the pipe-frame building system with plywood enclosure. Unskilled part-time student labor was also used for erecting this structure, and the work was done intermittently. The total man-hours required to complete the building could be reduced if troops were used for construction on a continuous basis.

3 FIELD TEST RESULTS

Cost Comparison

General

Three typical Army Facilities Components System (AFCS) building designs were chosen for the cost comparison because the paperboard and pipe-frame systems have anticipated usage similar to that of AFCS facilities (i.e., actual fabrication in a TO). The canvas-covered pipe-frame system was not included in the cost comparison because no similar AFCS design exists. Because of the various estimates which had to be made, the cost comparisons are only approximate and should not be used as the sole basis for selecting a system. Elements such as service life, equipment required for erection, and skill requirements should also be considered (see the *Design Criteria Evaluation* section).

The labor figures for the paperboard and pipe-frame systems were based on actual man-hours required to erect the complete building shell; material costs for these systems were based on actual costs. The material cost and labor requirement for the selected AFCS designs were taken from Tm 5-303.[2] A labor rate of $3/hr was set for both the AFCS and the experimental buildings to reflect troop labor costs. The cost of construction equipment was not considered.

Paperboard System

Table 1 summarizes the material and labor costs for fabrication and erection of the paperboard system. Excluding construction machine costs, the total cost of the paperboard building was $4057. Based on a total area of 510 sq ft (47.4 m^2), the cost per sq ft for the building was $7.95 ($85.57/m^2). This total was calculated based on a $2500 cost for the building itself (paperboard component). Based on the manufacturer's estimate, this figure would be reduced by approximately 30 percent should buildings be purchased in volume. The labor costs could also be reduced considerably if experienced troop labor was employed in lieu of part-time student labor.

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[2] *Army Facilities Components Systems--Logistic Data and Bills of Materials*, TM 5-303 (Department of the Army, 1965).

Table 1

Summary of Material and Labor Requirements of Paperboard Building

	Material	Labor*		Total
		Man-hours	Cost	
Paperboard Component	$2,500**	120	$360	$2,860
Insulation[#]	595	-	-	595
Raised Wood Foundation	149	29	87	236
Plywood Floor Panels	240	42	126	366
	$3,484	191	$573	$4,057

*Primarily reflects time requirements for part-time temporary personnel and a learning curve. Significant reduction is expected with experience.

**Significant decrease in cost is expected with large quantity purchases.

[#]Estimated cost including labor and material at $0.35/sq ft ($3.77/m^2).

Pipe-Frame System

Table 2 summarizes the material and labor costs for fabrication and erection of the pipe-frame system. Appendix B provides a more detailed breakdown of the material and labor requirements. Excluding construction machine costs, the total cost of the pipe-frame building was $3,579. Based on a total floor area of 504 sq ft (46.8 m^2), the cost of the building was $7.10/sq ft ($76.42/m^2). The total cost, which does not include painting and other miscellaneous costs, is believed to be appropriate for comparison with AFCS designs, since no AFCS facility includes painting. The total cost of labor and materials could be reduced considerably if the materials were purchased in volume and experienced troop labor were employed instead of part-time student labor.

AFCS Designs

Three facilities representative of AFCS field-fabricated lumber-framed building designs were chosen from the AFCS inventory using TM 5-302[3] and TM 5-303. Two general-purpose facilities -- 340512 and 340514 (Figures 15 and 16) -- were chosen as more recent additions to the inventory and for their concrete and wood floor systems. Facility 340321 (Figure 17), a basic barracks building, was chosen for its raised floor system.

Facility 340512 is supported by a concrete floor slab with an integral foundation. Facility 340514 is raised above ground level over a crawl space, with a foundation wall supporting the floor system. The walls of both facilities are site-fabricated of 2 in. x 4 in. (51 mm x 102 mm) lumber, spaced on 24-in. (0.6-m) centers. The roof system uses 2 in. x 8 in. (51 mm x 203 mm) lumber to provide "W" trusses, with 2 in. x 8 in. (51 mm x 203 mm) purlins on 24-in. (0.6-m) centers. The roof covering materials are insulation board and corrugated metal. The external wall coverings are insulation board and plywood. Insulation provided in walls and ceilings is 2-in. (51-mm) fiberglass batts.

Facility 340321 is the basic 20 ft x 20 ft (6.1 m x 6.1 m) building block for earlier AFCS barracks. Additional facility members are required, such as 340322 to form a building with dimensions of 20 ft x 40 ft (6.1 m x 12.2 m); 340361 for exterior cladding; 340374 for an elevated floor system; and 340391 for an interior liner. Walls can be "stick-built" or built as panels; both have 2 in. by 4 in. (51 mm

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[3] *Army Facilities Components System--Designs*, TM 5-302 (Department of the Army, 1973).

Table 2

Summary of Material and Labor Requirements of Pipe-Frame Building

	Material	Labor		Total
		Man-hours	Cost	
Structural Frame System*	$1,404**	12	$ 36	$1,440
Raised Wood Foundation System	60	18	54	114
Plywood Floor System	801	44	132	933
Plywood Roof and Wall System	389	43	129	518
Insulation (1640 sq ft x 0.35)#	574	-	-	574
	$3,228	117	$351	$3,579

*Includes foundation posts.
**Includes cost required for custom fabricating frame components--about 105 man-hours. This time could be significantly reduced with mass production.
#Estimated cost including material and labor at $0.35/sq ft ($3.77/m^2).

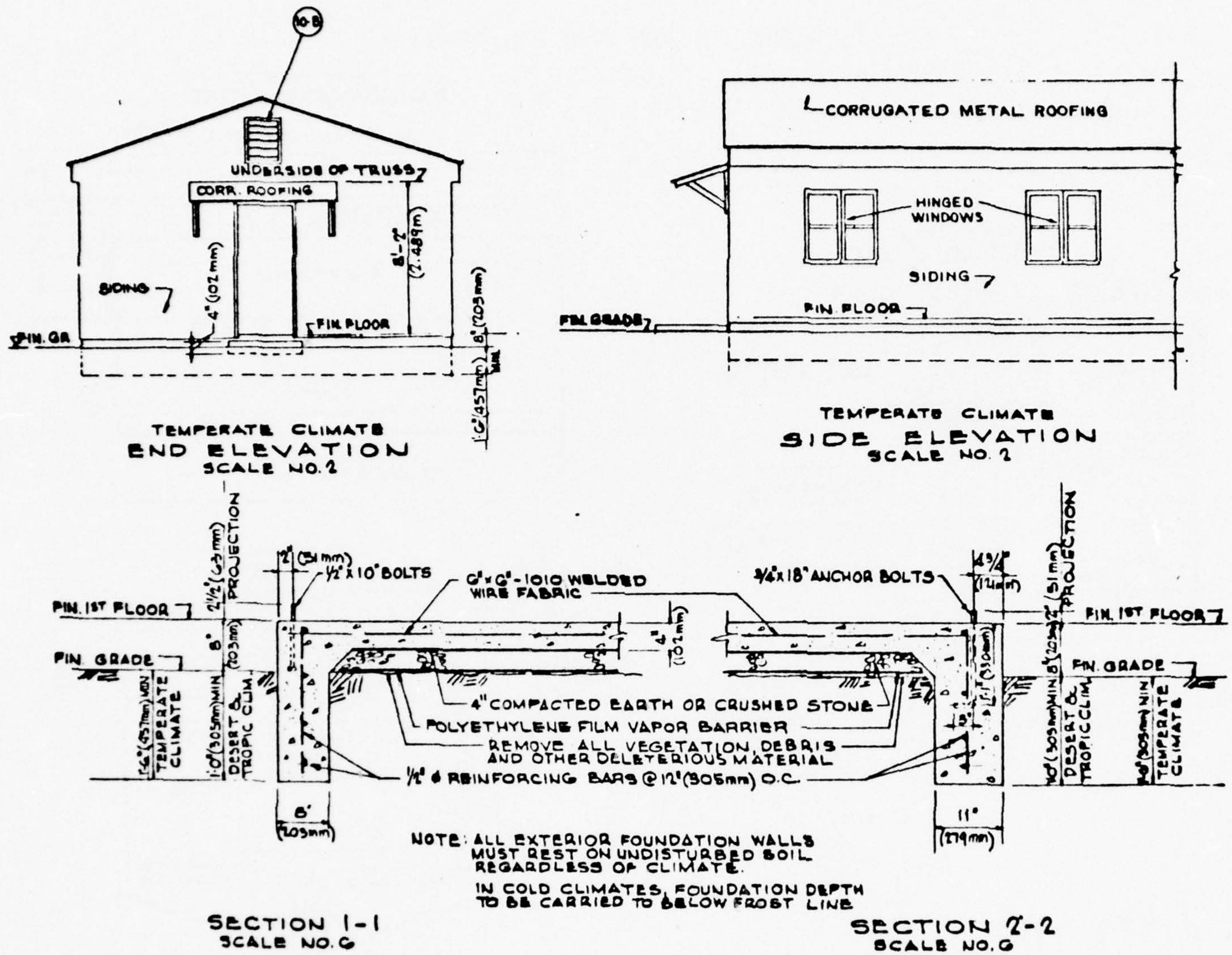


Figure 15. AFCS facility 340512.

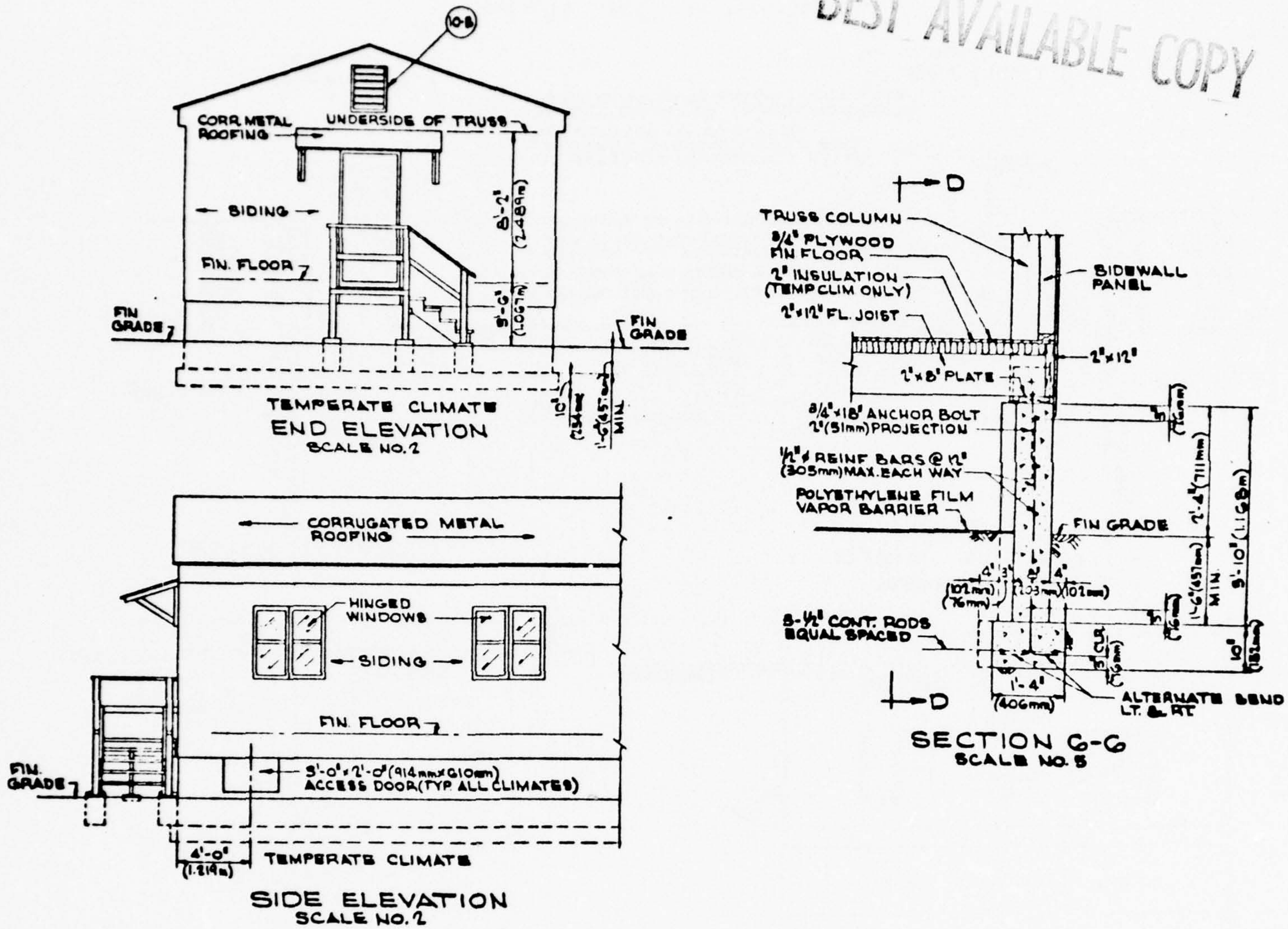
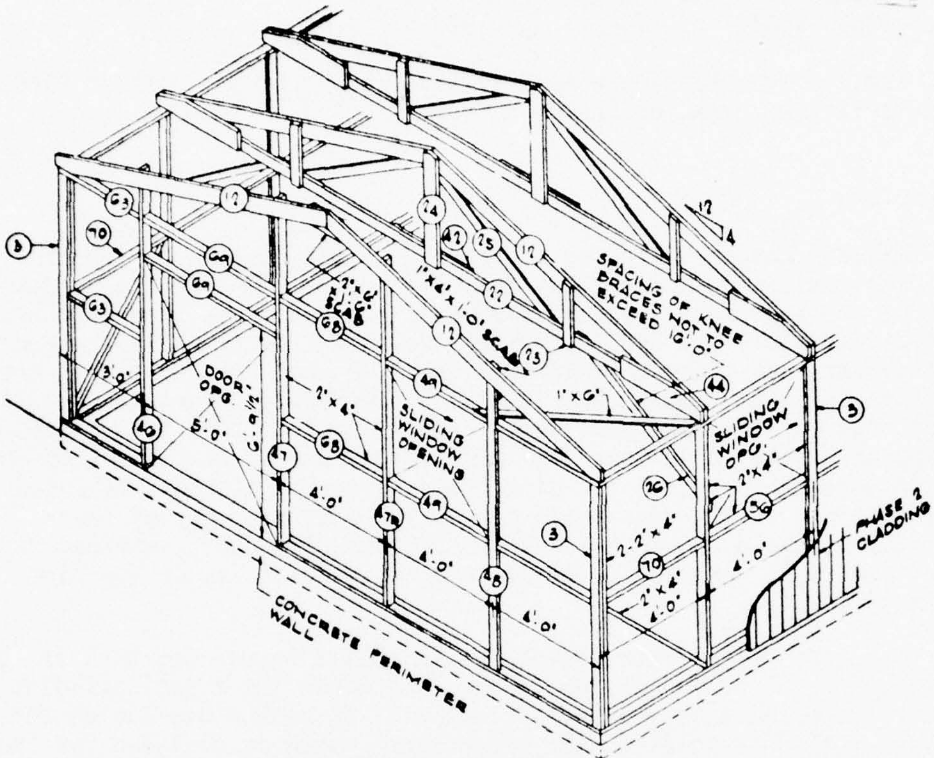


Figure 16. AFCS facility 340514.



TEMPERATE CLIMATE

TYPICAL FRAMING — BUILT-IN-PLACE CONSTRUCTION

20 FT. WIDE BUILDING SHOWN

SCALE NO. 5

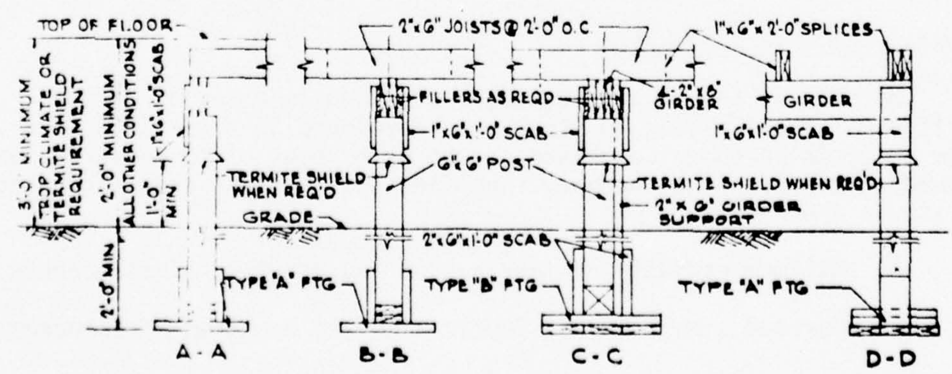


Figure 17. AFCS facility 340321. SI conversion factors: 1 ft = 0.3048 m; 1 in. = 2.54 cm.

x 102 mm) lumber on 48-in. (1.2-m) centers. The roof covering is asphalt roofing felt. Exterior cladding is 1-in. (25-mm) boards. Insulation is 3/4-in. (19-mm) insulation board.

Table 3 summarizes the material and labor requirements of these AFCS facilities based on the data from TM 5-303.

Comparison

Table 4 compares the costs of the AFCS facilities, paperboard building system, and pipe-frame building system. The cost per square foot of the paperboard system is 3 and 11 percent less than that of facilities 340512 and 340514, respectively, while the cost per square foot of the pipe-frame building system is 14 and 20 percent less than that of facilities 340512 and 340514, respectively. Facility 340321 (including supplemental facilities 340322, 340361, 340374, and 340391) is approximately 42 percent less expensive than the paperboard system and 35 percent less than the pipe-frame system. It should be noted that the cost of the paperboard system includes the cost of four aluminum single-hung windows and two preassembled doors, whereas no such items were included in either the AFCS facilities or the pipe-frame system.

The AFCS designs were developed to meet a 5-year design life, but have been capable of much longer use. Although the actual building life for the two experimental systems will be determined during the course of this field test, the pipe-frame system is designed for the 5-year requirement and the manufacturer of the paperboard system claims that it should also last at least 5 years. However, based on observation during the 9 months since the building was erected, the paperboard system has not weathered satisfactorily. The roof and wall panels have deformed considerably due to the combination of high humidity and intense heat. This effect is more apparent for both the south and the west walls.

Design Criteria Evaluation

Results of this field test were compared to a set of design criteria for evaluating TO structures developed in a previous study.[4] The criteria were derived based on the principles of TO construction: speed of construction, economy, and flexibility. The specific design criteria are:

1. Maximum rapidity of fabrication and erection of components

2. Maximum simplicity of fabrication and erection of components

3. Expandability

Table 3

Summary of Material and Labor Costs for Selected AFCS Designs

Facility	Description	Material Cost	Total Labor Man-hours	Total Labor Cost	Estimated Total Cost	Cost per sq ft (per m^2)
340512	20 ft x 40 ft (6.1 m x 12.2 m) general-purpose, basic building; wood frame with corrugated metal roof and plywood siding; insulated for temperate climate; concrete floor and foundation	$3,127	1,150	$3,450	$6,577	$8.22 ($88.48)
340514	Same as above, except for concrete footing and wood floor system	$3,956	1,323	$3,956	$7,925	$9.91 ($106.67)
340321	20 ft x 20 ft (6.1 m x 6.1 m) wood frame, basic barracks building; supplemented by following: 340322 - Additional 10-ft (3.0-m) wide bay (two) 340361 - Wood and felt cladding 340374 - Wood flooring 340391 - Insulation for wood frame building	$1,045	271	$813	$1,858	$4.65 ($50.05)

Table 4

Comparison of Cost Per Square Foot

Facility	Cost per sq ft (per m^2)
340512 (AFCS)	\$8.22 (\$88.48)
340514 (AFCS)	\$9.91 (\$106.67)
340321, 22, 61, 74, 91 (AFCS)	\$4.65 (\$50.05)
Paperboard Building System	\$7.95 (\$85.57)
Pipe-Frame Building System	\$7.10 (\$76.42)

4. Reductions in logistics, supply, and transport requirements including weight/volume ratio

5. Minimal additional training requirements for fabrication and erection of the building system

6. Reduction in building system costs

7. Reduction in operation, maintenance, and repair costs

8. Relocatability

9. Maintenance of a high degree of flexibility for commanders and military planners.

Maximum Rapidity of Fabrication and Erection of Components

The paperboard building can be erected very rapidly using unskilled labor. The wall and roof elements are precut or prefabricated, and hence require simple tools for erection; an air-powered staple gun, hammer, and some nails and staples are all that is required to erect the building. Repetition of operations during erection of the building expedites completion.

[4] R. L. Trent, T. M. Whiteside, and J. Robertus, *Field Experiment on a Prefabricated Expandable Foam/Wood Structure*, Interim Report C-50/ ADA032726 (CERL, 1976).

The pipe-frame building requires a supply of fabricated connectors and cannot be totally fabricated at the site. However, no special tools are required to erect the building. Most of the building's structural components can be erected on the ground and then raised into position by three or four men without using any special equipment.

Maximum Simplicity of Fabrication and Erection of Components

Both the paperboard and pipe-frame building systems are designed to be erected in a field environment. Both systems can be erected easily without using skilled labor, except for augering holes for foundation.

Expandability

The length of both building systems can be expanded by adding additional components in multiples of 16 in. (406 mm) for the paperboard system and 8 ft (2.4 m) for the pipe-frame system.

Reduction in Logistics, Supply, and Transport Requirement

Shipment of a 510-sq ft (47.4-m^2) paperboard building is estimated to take up approximately 2.2 STON (2.0 metric tons) and 6.45 MTON (7.4 m^3). A 504-sq ft (46.8-m^2) pipe-frame building is estimated to take up 3.7 STON (3.4 metric tons) and 4.1 MTON (4.7 m^3). These figures compare favorably with those of the AFCS designs--14 to 19 STON (12.7 to 17.2 metric tons) and 22 to 48 MTON (25.1 to 54.7 m^3) for 800-sq ft (74.3-m^2) buildings.

Minimum Additional Training Requirements for Fabrication and Erection of the Building System

No special training of personnel is required for erecting either system. Both systems were erected by untrained labor at CERL. Since fabrication of pipe elbows requires some skilled labor, they must be prefabricated and shipped to the site. For the paperboard structure, the paperboard components must be prefabricated. Sealing of the construction joints in the paperboard structure using fiberglass gel was performed by an experienced laborer at CERL. However, observations of this task indicate that training personnel to perform it would not be difficult. In addition, several adhesive tapes that can be used to seal the joints are available, thus eliminating the requirement for any skilled labor for the task.

Reduction in Building System Costs

The costs of the two experimental building systems are less than those of two of the three AFCS designs used for the comparison. Although the differences in cost are not significant, the differences in labor requirements are quite significant (Tables 1, 2, and 3).

Reduction in Operation, Maintenance, and Repair Costs

These costs will be evaluated when enough information is obtained.

Relocatability

No test of the relocatability of these buildings has been conducted. However, it is believed that most of the pipe-frame components can be reused without major repair. The paperboard building system is not considered to be relocatable.

Maintenance of a High Degree of Flexibility for Commanders and Military Planners

Both systems are designed to provide shelters that can be erected in a TO by troops without unusual equipment or excess manpower. Both structures can be erected easily, as required by non-CE troops. Fabrication of the building systems can be modified as needed. The commander can determine the degree of austerity to be supplied by the systems. Site preparation is minimal if a raised wood foundation system is used.

4 ADDITIONAL BUILDING CONCEPTS DEVELOPMENT

This section summarizes the results of a building concepts development study conducted for CERL by faculty members and students of the University of Illinois at Urbana-Champaign Department of Architecture. The objective of this study was to develop additional feasible building systems for possible inclusion in the family of TO structures. Appendix C contains a detailed description of this development study.

A two-part development plan was adopted based on the general design guidelines developed for the study (Annex C1). Development Plan I, which followed a structured approach, started at a general level and proceeded toward the specific. Development Plan II, which was less structured, solicited building system ideas from architectural students through a design competition. A total of 17 building concepts (seven under Development Plan I and 10 under Development Plan II) were developed. Appendix C describes each design concept.

The design alternatives from Development Plan I were evaluated based on the following 12 data items (see Annex C2 for definition of these items):

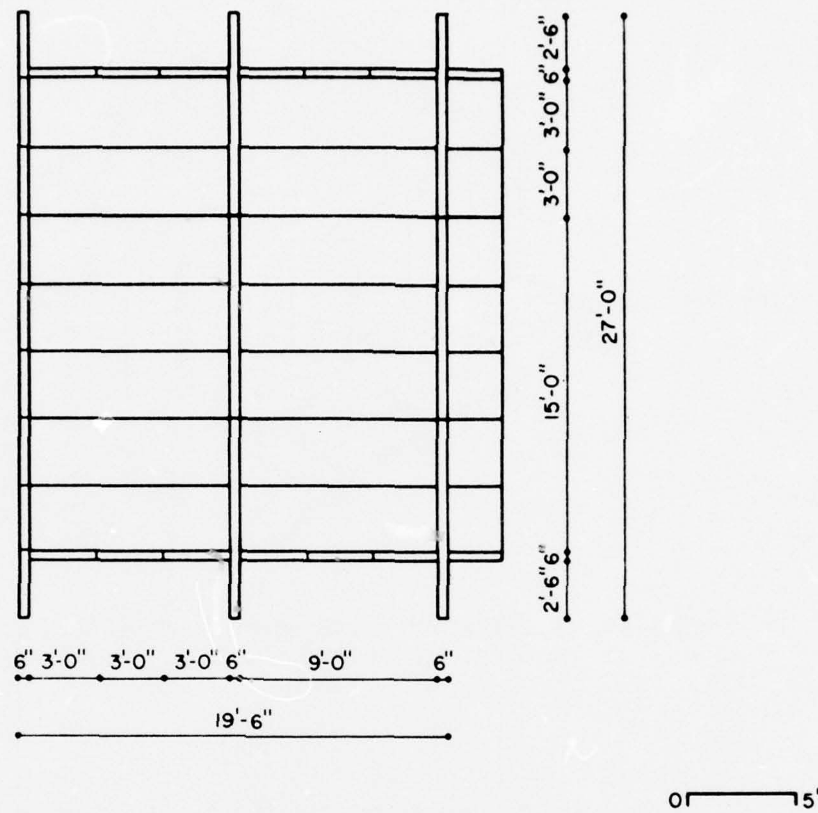
1. Perimeter of roof, wall, and floor members
2. Usable floor area efficiency
3. Size of bay
4. Volume per element and bay
5. Established time of assembly per bay
6. Net floor area
7. Number of connections per bay
8. Number of connections per square foot
9. Linear feet of joint per bay
10. Linear feet of joint per square inch
11. Number of panels per bay
12. Number of panels per square foot.

One design alternative was selected for possible further development. The selected alternative is assembled using a single panel element for all required structural components such as foundation,

floor beam, floor, column, exterior and interior wall, roof beam, roof, etc. The element has a dimensional ratio of 3:1 (3 ft x 9 ft x 6 in. [0.9 m x 2.7 m x 15.2 cm]). The panel's 3 ft 0 in. (0.9 m) dimension enables a single panel depth to be sufficient for all spans up to 48 ft (14.6 m). Figure 18 gives a plan and transverse cross section for a 24-ft (7.3-m) span basic shelter. In addition to the basic arrangement, other possible types of arrangements were studied. Figures 19 and 20 show two of these proposed complexes to illustrate the flexibility of the panel system.

The alternatives developed in Development Plan II were evaluated by a reviewing committee consisting of four members each from the University of Illinois Department of Architecture and CERL. Although the reviewers generally agreed that all alternatives were of excellent quality and met the basic criteria stated in the design guidelines, three unique proposals (proposals 3, 6, and 9) were identified as having great potential for further development.

Proposal 3 (Figure 21) is an interesting design which uses the typical panel while achieving light in the space. This solution has some very interesting details and jointing mechanisms. Proposal 6 (Figure 22) offers an extremely interesting solution which provides a unique floor and foundation system. Proposal 9 (Figure 23) appears to be easily assembled and transported and to minimize the number of elements. It also provides for water run-off.



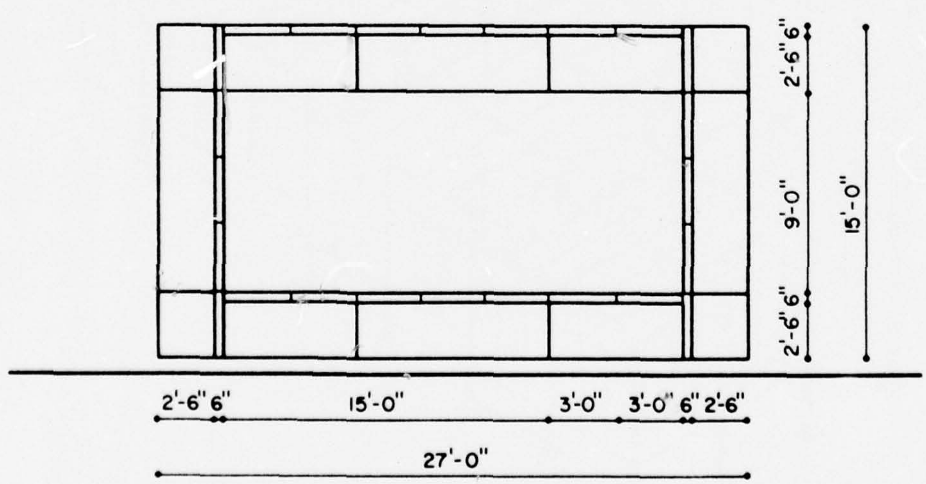


Figure 18. Plan and transverse cross section of 24-ft (7.3-m) wide shelter. SI conversion factors: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

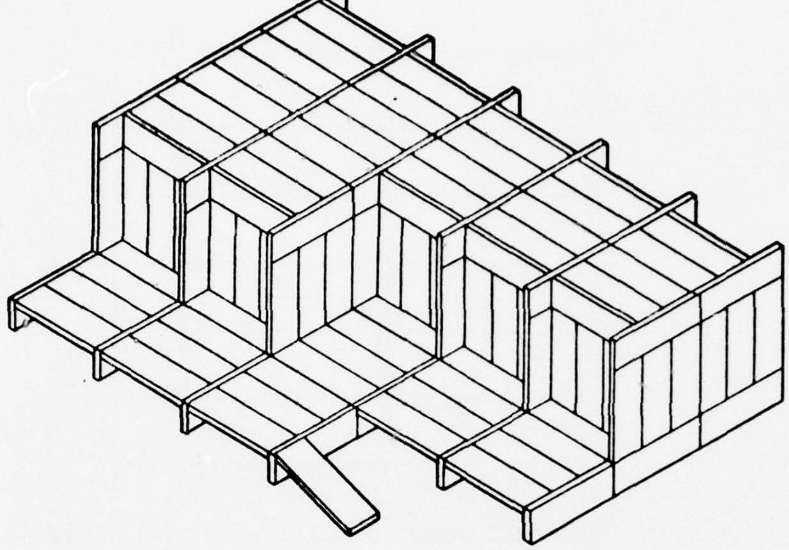


Figure 19. A different arrangement for shelters using 3 ft x 9 ft x 6 in. (0.9 m x 2.7 m x 15.2 mm) panels.

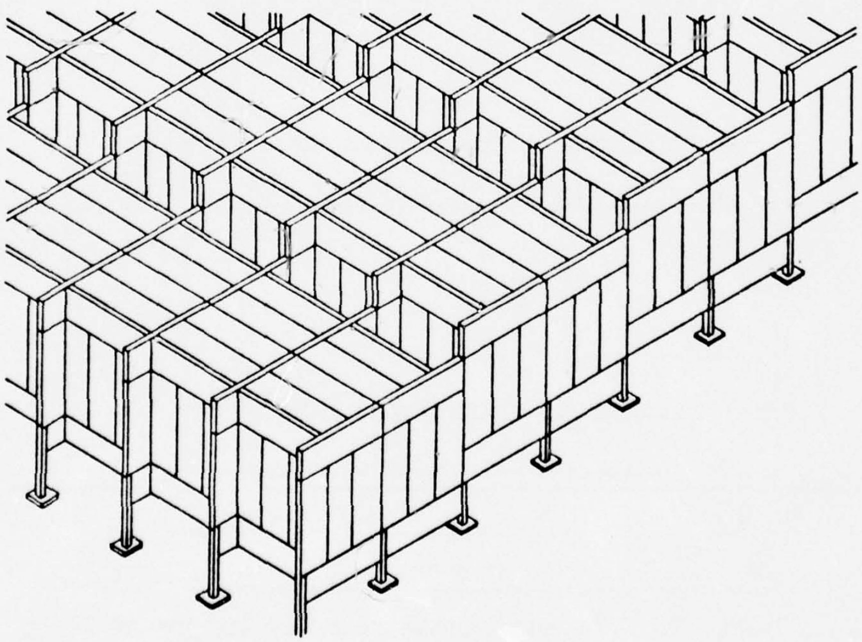


Figure 20. Another different arrangement for shelters using 3 ft x 9 ft x 6 in. (0.9 m x 2.7 m x 15.2 mm) panels.

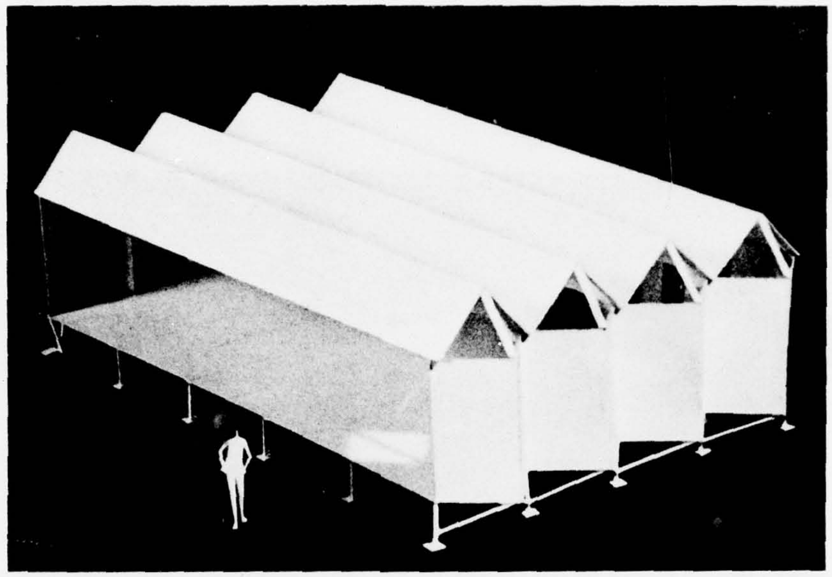


Figure 21. Proposal 3.

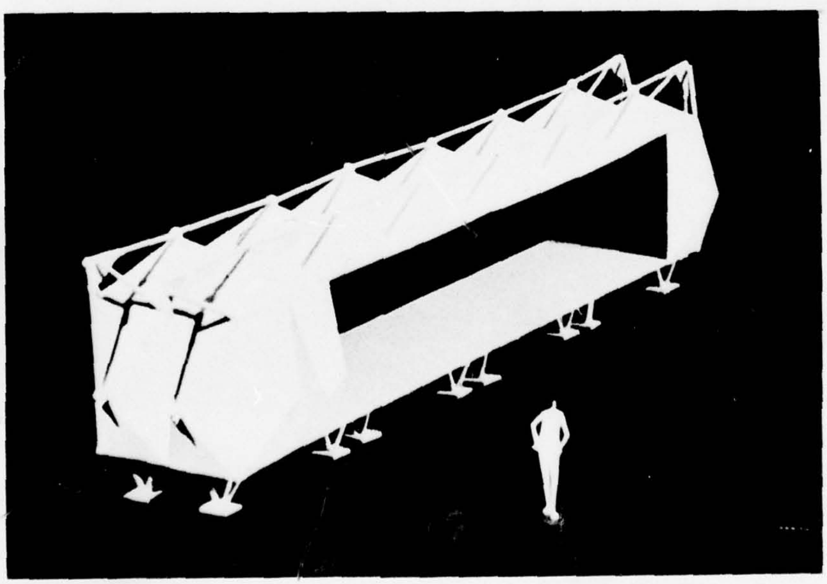


Figure 22. Proposal 6.

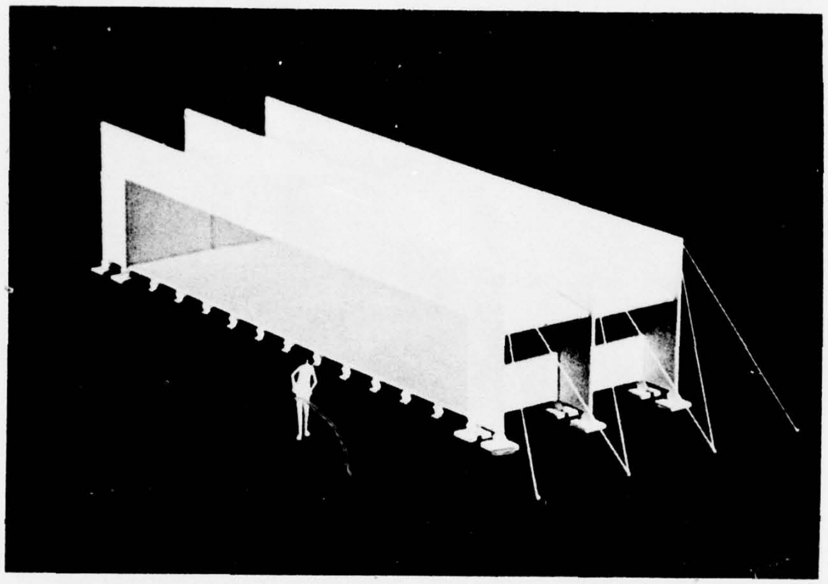


Figure 23. Proposal 9.

5 PERFORMANCE INSPECTION OF FOAM/WOOD BUILDING AT USAES

A 24 ft x 40 ft (7.2 m x 12.0 m) foam/wood panelized building was constructed at USAES in September and October of 1975.[5] The building was planned for use as a classroom as well as a demonstration facility.

The first yearly inspection of the building was conducted on 17 November 1976. The building appeared to have weathered and performed quite well during the first year in service. No structural deterioration was observed in any part of the building; foundation bents, floor, and wall and roof panels all appeared to be in very good condition. Neither the interior nor exterior of the building exhibited any wear and tear, primarily because the building has not been used as often as originally planned. No repairs have been made to the building.

Although paints on the exterior of wall panels have discolored slightly, probably due to mildew or use of low-quality paint (Figure 24), the plywood panels still appeared to be sound. There were some indications of rainwater seepage through the joints between the wall and floor panels (Figure 25), since the joints were not caulked.

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[5] R. L. Trent, T. M. Whiteside, and J. Robertus, *Field Experiment on a Prefabricated Foam/Wood Structure*, Interim Report C-50/ADA032726 (CERL, October 1976).

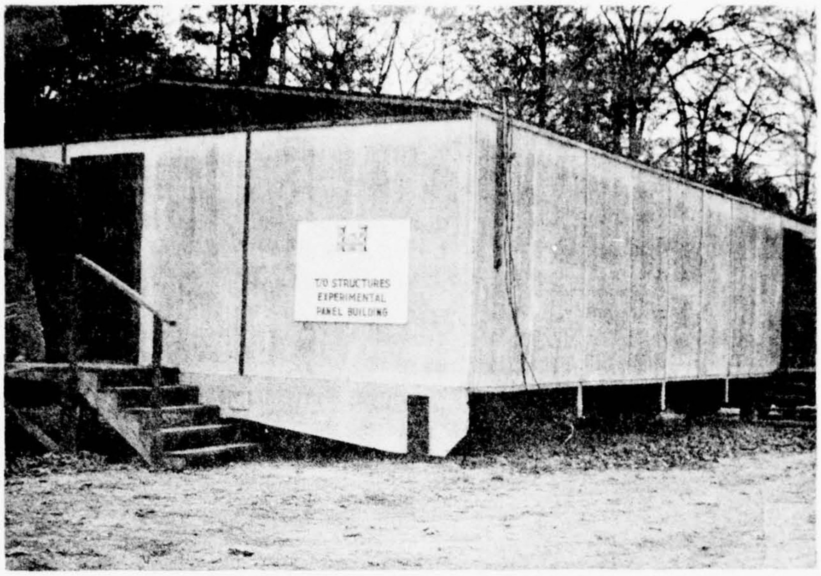

Figure 24. Foam/wood panelized building at USAES after year in service.

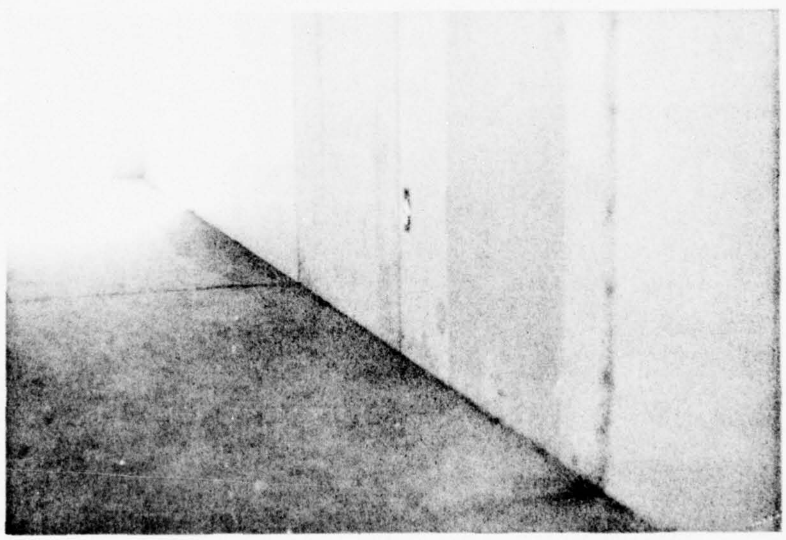

Figure 25. Indications of rainwater seepage along wall and floor panels.

6 CONCLUSIONS

Field Experiment

The field test of the paperboard system has shown that the building system can be erected without using skilled labor or special tools. The system can be easily packed and shipped in a container. However, without applying any backing material such as polyurethane or other rigid foam material to increase their stiffness and/or dimensional stability, both roof and wall panels have deformed considerably due to the combination of high humidity and intense heat.

Another drawback of the paperboard system is that it requires good protection from moisture before erection and application of fiberglass gel after erection because the paperboard will delaminate if it is dampened. Unless a better treatment for water resistance is developed, the system's potential for application for TO housing is not promising.

The pipe-frame building system concept has been proved to be a viable system for TO use. The system can be erected easily without using skilled labor and special tools; it takes only 12 man-hours of unskilled student labor to erect the pipe-frame system. The building is relocatable, expandable, and readily modified for longer term usage. However, the structural pipes and elbow joints require prefabrication. Effort should be made to investigate the possibility of using joint members available in the TO to avoid the long lead time required to contract for manufacture of elbow joints.

The costs of both systems are reasonable compared to those of the selected AFCS systems. The cost of labor can be reduced if experienced troop labor is employed in lieu of part-time student laborers. Costs of building materials can also be reduced by purchasing in large volumes. Data from the manufacturer of the paperboard building system indicate that the total reduction in overall construction cost (material and labor) will be about 30 percent.

Building Concepts Development

The building concepts developed in the concept development study were generally of very good quality and met the basic design criteria for TO use. Most of the design alternatives adopted a prefabricated or pre-engineered approach. While such prefabricated systems have some drawbacks, such as high initial cost and a requirement for heavy construction equipment, they do provide rapid deployment and erection in a TO. With some refinements and improvements, it is believed that several of the building concepts can be developed into effective building systems for use in a TO.

Performance Inspection of Foam/Wood Building

The foam/wood building erected at USAES has generally weathered quite satisfactorily during its first year in service, except for slight rainwater seepage along the joints. This problem can be solved by caulking along the joints.

APPENDIX A:

PARTS LIST OF PAPERBOARD STRUCTURE

No.	Description	Nominal Size
42	Standard Wall Panel	30 in. x 103 in. (762 mm x 2.6 m)
4	(10 in. [25.4 mm) wide) Wall Panel	24 in. x 103 in. (700 mm x 2.6 m)
4	(11 3/4 in. [29.8 mm] wide) Wall Panel	26 in. x 103 in. (660 mm x 2.6 m)
4	Standard Corner Panel	30 in. x 103 in. (762 mm x 2.6 m)
10	Standard Header	30 in. x 25 in. (762 mm x 635 mm)
8	Lower Window (28 in. x 30 in.) [711 mm x 762 mm]	30 in. x 58 in. (762 mm x 1.5 m)
2	(13 in. [330 mm] wide) Door Side (3 ft 0 in. x 6 ft 8 in. [0.9 m x 2.0 m])	27 in. x 103 in. (686 mm x 2.6 m)
2	(18 3/4 in. [476 mm] wide) Door Header (3 ft 0 in. x 6 ft 8 in. [0.9 m x 2.0 m])	33 in. x 21 in. (838 mm x 53.3 cm)
32	Roof Panels (18 ft 0 in./20 ft 7 1/2 in. [5.5 m/6.3 m]) wide	30 in. x 162 in. (762 mm x 4.1 m)
2	End Roof (101 B/Right)	27 in. x 162 in. (686 mm x 4.1 m)
2	End Roof (101 B/Left)	27 in. x 162 in. (686 mm x 4.1 m)
28	4 Sets @ 7 Parts Gable End	Av. 30 in. (762 mm)
4	(10 in. [254 mm] wide) 101 B-Top Gable End	Av. 24 in. (700 mm)

144 Parts Lumber

No.	Description	Nominal Size
4	Top Plate Front/Rear Wall	2 in. x 8 in. (51 mm x 203 mm) 9 ft 2 in.(2.8 m) Long
4	Top Plate Side Walls	2 in. x 8 in. (51 mm x 203 mm) 10 ft 3 3/4 in. (3.1 m) Long

No.	Description	Nominal Size
2	Top Plate Door Section	2 in. x 8 in. (51 mm x 203 mm) Nom. 5 ft 4 in. (1.7 m) Long
1	Beam I	2-2 in. x 10 in. x 10 ft (51 mm x 254 mm x 3.1 m)
1	Beam II	2-2 in. x 10 in. x 13 ft 10 in. (51 mm x 254 mm x 4.2 m)
1	Center Post	2-2 in. x 4 in. x 12 ft 0 in. (51 mm x 102 mm x 7.0 m)
2	End Wall Post	2-2 in. x 4 in. x 11 ft 10 1/2 in. (51 mm x 102 mm x 3.6 m)
6	Beam Seat (Straps)	3 in. x 16 in. x 3/8 in. (51 mm x 408 mm x 391 mm) Plywood
18	Roof Fastener	2 in. x 4 in. x 15 in. (51 mm x 102 mm x 381 mm)
50	Base Plate	6 in. x 15 in. (152 mm x 381 mm) 3/8 in. (9 mm) Plywood
4	Corner Base Plate	6 in. x 14 in. (152 mm x 356 mm) 3/8 in. (9 mm) Plywood
4	(11 3/4 in. [298 mm] wide) Base Plate Front/Rear	6 in. x 11 in. (152 mm x 279 mm) 3/8 in. (9 mm) Plywood
4	(10 in. [254 mm] wide) Base Plate Endwalls	6 in. x 7 in. (152 mm x 178 mm) 3/8 in. (9 mm) Plywood
2	(13 in. [330 mm] wide) Base Plate Door Section	6 in. x 12 in. (152 mm x 305 mm) 3/8 in. (9 mm) Plywood
2	Fascia Front/Rear Wall	1 in. x 6 in. (25 mm x 152 mm) 24 ft 10 in. (7.6 m) Long
2	Fascia Endwall Right	1 in. x 6 in. (25 mm x 152 mm) 12 ft 6 in. (3.8 m) Long
4	Window (Alum S. H.)	28 in. x 30 in. (711 mm x 762 mm)
1	Door H. C. Wood Plush	3 ft 0 in. x 6 ft 8 in. (0.9 m x 2.0 m)
1	Door H. C. Wood Plush	2 ft 6 in. x 6 ft 8 in. (0.8 m x 2.0 m)
2	Lockset	

APPENDIX B:

DETAILED COST BREAKDOWN OF MATERIAL AND LABOR REQUIREMENTS FOR PIPE-FRAME BUILDING SYSTEM

	Plywood Enclosure		Canvas Enclosure	
	Labor	Mat'l Cost	Labor	Mat'l Cost
	Man-hours	$	Man-hours	$
Fabricate pipe frame and connectors*	81	1059	57	705
Paint pipe	24	30	17	20
Steel erection	12	—	14	—
Auger foundation holes	2.5	—	1.5	—
Place foundation posts	10	—	6	—
Pour concrete	5.6	60	4.2	45
Joist hangers	3.6	102	2.4	68
Floor joists	9	429	5	286
Floor panels fabrication	18	189	12	126
Install floor panels	13.2	81	8.8	56
Roof and wall panel fabrication	18	189	—	600
Roof and wall panel erection	25	200	12	—
Clear site	4	—	4	—
Layout site	1.33	—	1.33	—

*Including foundation post.

APPENDIX C:

ADDITIONAL BUILDING CONCEPTS DEVELOPMENT

This appendix presents the results of the building concepts development study conducted for CERL by faculty members and students of the University of Illinois Department of Architecture. The objective of this study was to develop additional feasible building systems for possible inclusion in the family of TO structures.

Study Approach

A two-part development plan was adopted based on the general design guidelines (see Annex C1): Development Plan I followed a structured approach, whereas Development Plan II followed an unstructured approach. Development Plan I started at a general level and proceeded toward the specific. The plan included three steps: Step 1 involved a general look at various basic shelter configurations and an attempt to determine and focus on one configuration type; Step 2 involved developing several preliminary designs based on one configuration type to determine a single, specific direction in which to proceed; and Step 3 involved developing one specific design proposal in an attempt to determine the specific shelter characteristics. Development Plan II solicited building system ideas from architectural students through a design competition. This provided a range of alternatives.

Development Plan I

Development Plan I followed the procedures illustrated in Figure C1. Each step contained three parts: description, evaluation, and product/conclusion. Activities in each part of each step are described in the following sections.

Description of Various Shelter Configurations (Step 1A)

The initial step in Development Plan I was to assume and describe a variety of configurations and to try to determine the most efficient and effective basic shelter configuration. Six basic shelter configurations (Figure C2) were assumed: A-frame, flat, shed, gable, mansard, and barrel.

Each configuration was described using the 12 items of data listed in Chapter 4. Three different widths (12 ft, 24 ft, and 48 ft [3.7 m, 7.3 m, and 14.6 m]) were considered for each configuration.

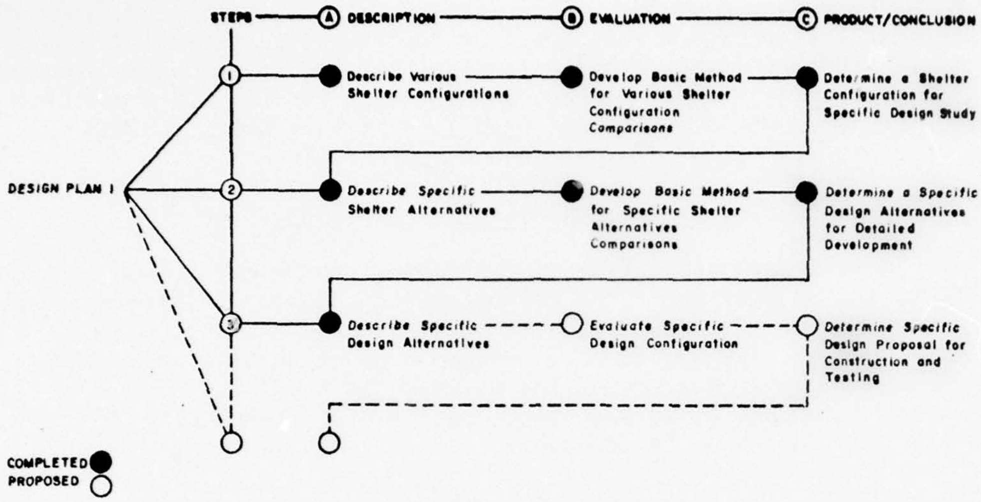

Figure C1. Development Plan I.

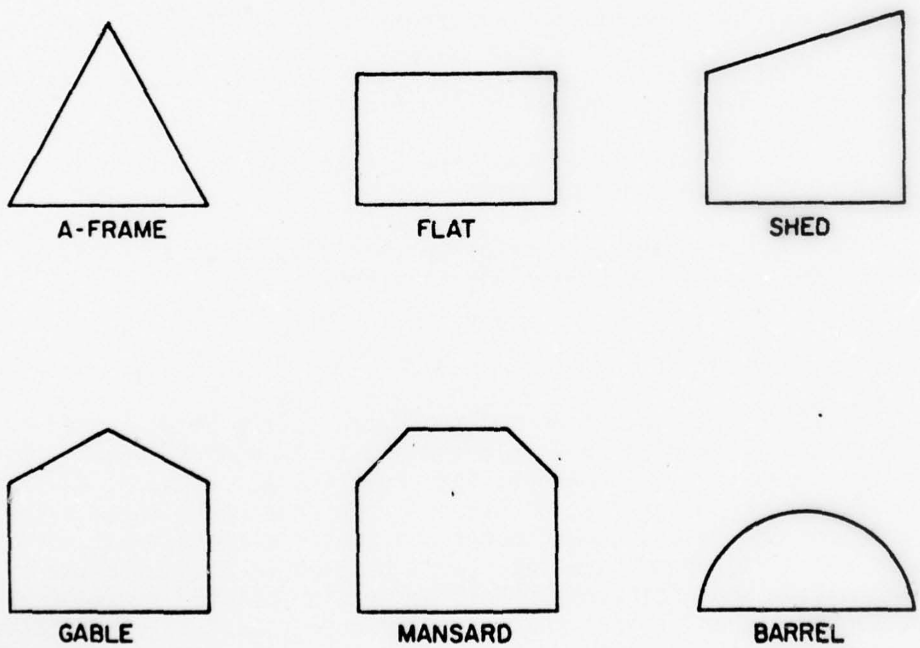

Figure C2. Shelter configurations.

Evaluation of Various Shelter Configurations (Step 1B)

Tables C1 through C3 summarize the data for each configuration for the three building widths. These data were used to compare, score, and rank the configurations based on the assumed data definitions and description. Configuration comparisons were made separately for each type at each length (12 ft, 24 ft, and 48 ft [3.7 m, 7.3 m and 14.6 m]) and for the combined scores of each type at all three lengths.

Product/Conclusion - Most Suitable Configuration (Step 1C)

To rank each configuration in terms of numerical scores, the configuration or configurations demonstrating the most desirable characteristics under a certain heading were given the highest score -- three points. The second most desirable configuration under that heading was given a score of two points, and the least desirable configuration was given a score of one point. These scores are summarized in Tables C4 through C7.

Based on the scores assigned, the following conclusions were made:

1. Configuration 2 (flat or rectangular) offers the most efficient use of space in all categories.

2. Configuration 6 (barrel) ranks second overall.

3. Configurations 1 (A-frame) and 6 (barrel) become less efficient at larger sizes (48 ft [14.6 m]).

4. Configurations 3 (shed) and 5 (mansard) scored lowest overall and were never higher than fourth.

5. The ideal shape is obtained when gross area is equal to net area. Configuration 2 meets this requirement

Description of Specific Shelter Alternatives (Step 2A)

Based on the evaluation and conclusions from Step 1, configuration 2 (flat or rectangular) was selected for further development. Seven preliminary design alternatives (alternatives 1, 2, 2A, 3, 4, 5, and 5A) were developed for evaluation purpose. In developing these alternatives, the intent was to design and develop a single element, unit, or component that, when assembled, could be used to form both the structural system and enclosures. This assumption pointed toward the development of an element that could be used to act as a foundation, floor beam, floor, column, exterior and interior wall, roof beam, roof, stair, ramp, door, and window. It was realized that there would be a

Table C1

Building Data for 12-ft (3.7-m) Wide Shelter Configuration

	Configuration					
	A-Frame	Flat	Shed	Gable	Mansard	Barrel
Wall member length, ft (m)	12 (3.7)	8 (2.4)	8,16 (2.4, 4.9)	8 (2.4)	8 (2.4)	-
Perimeter of roof and wall members, ft (m)	24 (7.3)	28 (8.5)	38.4 (11.7)	33 (10.1)	31.2 (9.5)	22.84 (7.0)
Perimeter of roof, wall, and floor members, ft (m)	36 (11.0)	40 (12.2)	50.4 (15.4)	45 (13.7)	43.2 (13.2)	34.84 (10.6)
Number of wall members	0	2	2	2	2	-
Number of roof members	2	1	1	2	3	1
Number of unlike members/total	0	2	4	3	4	2
Number of total members	3	4	4	5	6	2
Number of total joints	3	4	4	5	6	2
Area of configuration, sq ft (m^2)	62.37 (5.8)	96 (8.9)	144 (13.4)	132 (12.3)	128 (11.9)	80.5 (7.5)
Area for standing (8 ft [3.4 m] ht., sq ft (m^2)	16 (1.5)	96 (8.9)	96 (8.9)	96 (8.9)	96 (8.9)	80.5 (7.5)
Area for sitting (6 ft [1.8 m] ht.), sq ft (m^2)	30 (2.8)	72 (6.7)	72 (6.7)	72 (6.7)	72 (6.7)	66.75 (6.2)
Usable area efficiency, %	54.5	100	67	72.7	73	100

Table C2

Building Data for 24-ft (7.3-m) Wide Shelter Configuration

	Configuration					
	A-Frame	Flat	Shed	Gable	Mansard	Barrel
Wall member length, ft (m)	24 (7.3)	8 (2.4)	8, 16 (2.4, 4.9)	8 (2.4)	8 (2.4)	-
Perimeter of roof and wall members, ft (m)	48 (14.6)	40 (12.2)	49.3 (15.0)	42.8 (13.0)	41.8 (12.7)	37.68 (11.5)
Perimeter of roof, wall, and floor members, ft (m)	72 (21.9)	64 (19.5)	73.3 (22.3)	66.8 (20.4)	65.8 (20.1)	61.68 (18.8)
Number of wall members	0	2	2	2	2	-
Number of roof members	2	1	1	2	3	1
Number of unlike members/total	0	2	4	3	4	2
Number of total members	3	4	4	5	6	2
Number of total joints	3	4	4	5	6	2
Area of configuration, sq ft (m^2)	249 (23.1)	192 (17.8)	288 (26.8)	264 (24.5)	258 (24.0)	226 (21.0)
Area for standing (8 ft [3.4 m] ht.), sq ft (m^2)	120 (11.1)	192 (17.8)	192 (17.8)	192 (17.8)	192 (17.8)	172 (16.0)
Area for sitting (6 ft [1.8 m] ht.), sq ft (m^2)	102 (9.5)	144 (13.4)	144 (13.4)	144 (13.4)	144 (13.4)	135 (12.5)
Usable area efficiency, %	53	100	67	72.7	73	76

Table C3

Building Data for 48-ft (14.6-m) Wide Shelter Configuration

	Configuration					
	A-Frame	Flat	Shed	Gable	Mansard	Barrel
Wall member length, ft (m)	48 (14.6)	8 (2.4)	8, 16 (2.4, 4.9)	8 (2.4)	8 (2.4)	-
Perimeter of roof and wall members, ft (m)	96 (29.3)	54 (16.5)	72.7 (22.2)	65.4 (19.9)	65.3 (19.9)	75.36 (23.0)
Perimeter of roof, wall, and floor members, ft (m)	144 (43.9)	102 (31.1)	120.7 (36.8)	113.4 (34.6)	113.3 (34.6)	123.36 (37.6)
Number of wall members	0	2	2	2	2	-
Number of roof members	2	1	1	2	3	1
Number of unlike members/ total	0	2	4	3	4	2
Number of total members	3	4	4	5	6	2
Number of total joints	3	4	4	5	6	2
Area of configuration, sq ft (m^2)	996 (92.5)	384 (35.7)	576 (53.5)	688 (63.9)	528 (49.1)	904.32 (84.0)
Area for standing (8 ft [3.4 m] ht.), sq ft (m^2)	312 (29.0)	384 (35.7)	384 (35.7)	384 (35.7)	384 (35.7)	376 (34.9)
Area for sitting (6 ft [1.8 m] ht.) sq ft (m^2)	252 (23.4)	288 (26.8)	288 (26.8)	288 (26.8)	288 (26.8)	285 (26.5)
Usable area efficiency, %	33.13	100	67	72.7	73	41.6

Table C4

Scores for 12-ft (3.7-m) Wide Shelter Configuration

	Configuration					
	A-Frame	Flat	Shed	Gable	Mansard	Barrel
Wall member length, ft	1	2	1	2	2	3
Perimeter of roof and wall members, ft.	3	2	1	2	2	3
Perimeter of roof, wall, and floor members in ft	3	2	1	2	2	3
Number of wall members	3	2	1	2	2	3
Number of roof members	2	3	3	2	1	2
Number of unlike members/ total	3	2	1	2	1	2
Number of total members	3	2	2	1	1	3
Number of total joints	3	2	2	1	1	3
Area of configuration in sq ft	1	3	1	2	2	1
Area for standing (8 ft ht.), sq ft	1	3	1	2	2	1
Area for sitting (6 ft ht.), sq ft	1	3	1	2	2	1
Usable area efficiency, %	1	3	1	2	2	1
Total	25	29	16	24	20	24
Percentage (%)	69.4	80.5	44.4	66.6	55.5	66.6

SHELTERS/EVALUATION/12 FT CONFIGURATION

Table C5

Scores for 24-ft (7.3-m) Wide Shelter Configuration

	Configuration					
	A-Frame	Flat	Shed	Gable	Mansard	Barrel
Wall member length, ft	1	2	1	2	2	3
Perimeter of roof and wall members, ft	1	2	1	2	2	3
Perimeter of roof, wall, and floor members in ft	1	2	1	2	2	3
Number of wall members	3	2	1	2	2	3
Number of roof members	2	3	3	2	1	2
Number of unlike members/total	3	2	1	2	1	2
Number of total members	3	2	2	1	1	3
Number of total joints	3	2	2	1	1	3
Area of configuration in sq ft	1	3	1	2	2	2
Area for standing (8 ft ht.) in sq ft	1	3	1	2	2	2
Area for sitting (6 ft ht.) in sq ft	1	3	1	2	2	2
Usable area efficiency %	1	3	1	2	2	2
Total	22	29	16	22	20	30
Percentage (%)	61.1	80.5	44.4	61.1	55.5	83.3

SHELTERS/EVALUATION/24 FT CONFIGURATION

Table C6

Scores for 48-ft (14.6-m) Wide Shelter Configuration

	Configuration					
	A-Frame	Flat	Shed	Cable	Mansard	Barrel
Wall member length, ft	1	2	1	2	2	3
Perimeter of roof and wall members, ft	1	3	2	2	2	2
Perimeter of roof, wall, and floor members in ft	1	3	2	2	2	2
Number of wall members	3	2	1	2	2	3
Number of roof members	2	3	3	2	1	2
Number of unlike members/total	3	2	1	2	1	2
Number of total members	3	2	2	1	1	3
Number of total joints	3	2	2	1	1	3
Area of configuration in sq ft	1	3	2	2	2	1
Area for standing (8 ft ht.) sq ft	1	3	2	2	2	1
Area for sitting (6 ft ht.) sq ft	1	3	2	2	2	1
Usable area efficiency %	1	3	2	2	2	1
Total	21	31	21	22	20	24
Percentage %	58.3	86.1	58.3	61.1	55.5	66.6

SHELTERS/EVALUATION/48 FT CONFIGURATION

Table C7

Combined Scores of 12-ft, 24-ft, and 48-ft (3.7-m, 7.3-m, and 14.6-m) Shelter Configurations

	Configuration					
	A-Frame	Flat	Shed	Gable	Mansard	Barrel
Wall member length, ft	1	2	1	2	2	3
Perimeter of roof and wall members ft	1.66	2.33	1.33	2	2	2.66
Perimeter of roof, wall, and floor members in ft	1.66	2.33	1.33	2	2	2.66
Number of wall members	3	2	1	2	2	3
Number of roof members	2	3	3	2	1	2
Number of unlike members/total	3	2	1	2	1	2
Number of total members	3	2	2	1	1	3
Number of total joints	3	2	2	1	1	3
Area of configuration, sq ft	1	3	1.33	2	2	1.33
Area for standing (8 ft ht.), sq ft	1	3	1.33	2	2	1.33
Area for sitting (6 ft ht.), sq ft	1	3	1.33	2	2	1.33
Usable area efficiency %	1	3	1.33	2	2	1.33
Total	22.32	29.66	17.98	22	20	26.64
Percentage (%)	62	82.66	49.94	61.11	55.55	74

SHELTERS/EVALUATION CONCLUSION/DATA

certain degree of inefficiency in using a single element, since the panels would have to be designed for the maximum loading conditions. However, a simple panel could be mass produced and would be capable of forming various shelter configurations and arrangements, thus making the tradeoff worth pursuing.

Two design philosophies were adopted in the development of the alternatives: (1) to design for the minimum size shelters (e.g., 12-ft [3.7-m] and 24-ft [7.3-m] spans), developing a system in which smaller shelters could be connected to span the 48-ft (14.6-m) span shelter and (2) to design for the maximum size shelter (48-ft [14.6-m] span), thus providing the appropriate capabilities for the 12-ft (3.7-m) and 24-ft (7.3-m) shelters. Alternative 1 was based on the first philosophy, while the remaining alternatives were based on the second.

1. Design alternative 1 uses a single panel element with a 4:1 dimensional ratio (2 ft x 8 ft x 3 in. [0.6 m x 2.4 m x 76 mm]). Figure C3 shows a plan and transverse cross section of a typical 24-ft (7.3-m) wide shelter using 2 ft x 8 ft x 3 in. [0.6 m x 2.4 m x 76 mm] panels. In this design, the structural application of the panels for roof beams requires only one panel in depth (2 ft 0 in. [0.6 m]) for the 12-ft (3.7-m) and 24-ft (7.3-m) spans. For the 48-ft (14.6-m) span, the depth of the roof beam must be increased to 4 ft 0 in (1.2 m). The typical transverse cross section for a 48-ft (14.6-m) span shelter is shown in Figure C4.

2. Design alternative 2 is assembled using a panel element with a 3:1 dimensional ratio (3 ft x 9 ft x 6 in. [0.9 m x 2.7 m x 152 mm]). The 3 ft 0 in. (0.9 m) dimension of the panel enables a single panel depth to be sufficient for all spans. Figure C5 gives a plan and transverse cross section for a 21-ft (6.4-m) span shelter.

3. Design alternative 2A is similar to design alternative 2 in that it uses the same 3 ft x 9 ft x 6 in. (0.9 m x 2.7 m x 152 mm) panel. The differences are in the position of the side walls and the resultant placing of the roof and floor panels. The side walls are positioned so that the interior face of the wall is on the centerline of the columns. This positioning necessitates off-setting the floor and roof panel joints at the half module point. The resultant increase of panels provides an additional 3 ft 0 in. (0.9 m) to the interior of all shelter designs, while the spans remain the same as in alternative 2. Figures C6 shows a typical plan and transverse cross section.

4. Design alternative 3 uses a single panel element with a 3:1 dimensional ratio (3 ft x 9 ft x 6 in. [0.9 m x 2.7 m x 152 mm]). The arrangement of this alternative provides a protected location for openings into the shelter (e.g., doors, windows, and vents). Accomplishing this required the structural system, and the walls between columns were alternately aligned at the exterior and interior edges of the

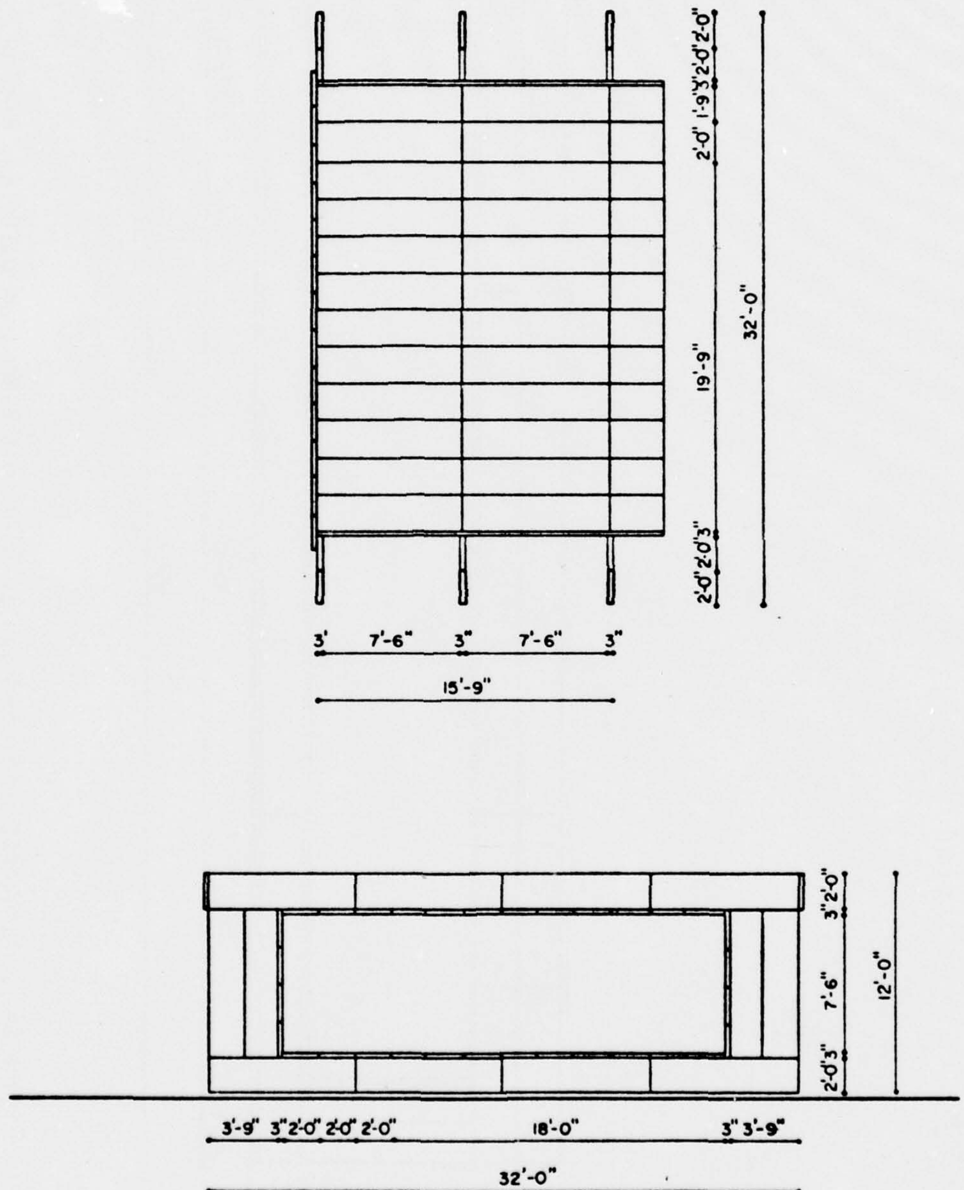

Figure C3. Plan and transverse cross section of 24-ft (7.3-m) wide shelter, design alternative 1. SI conversion factors: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

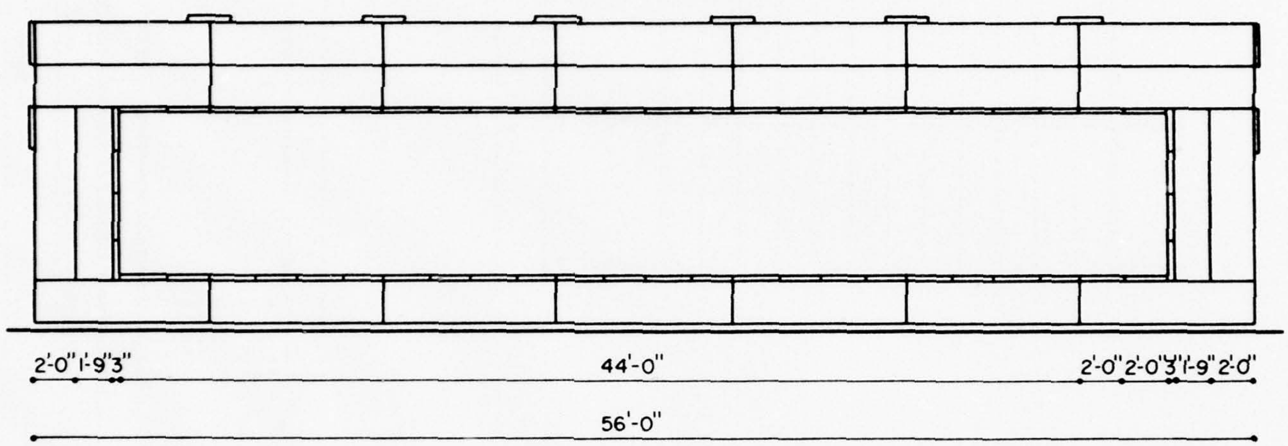

Figure C4. Transverse cross section of 48-ft (14.6-m) span building, design alternative 1. SI conversion factors: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

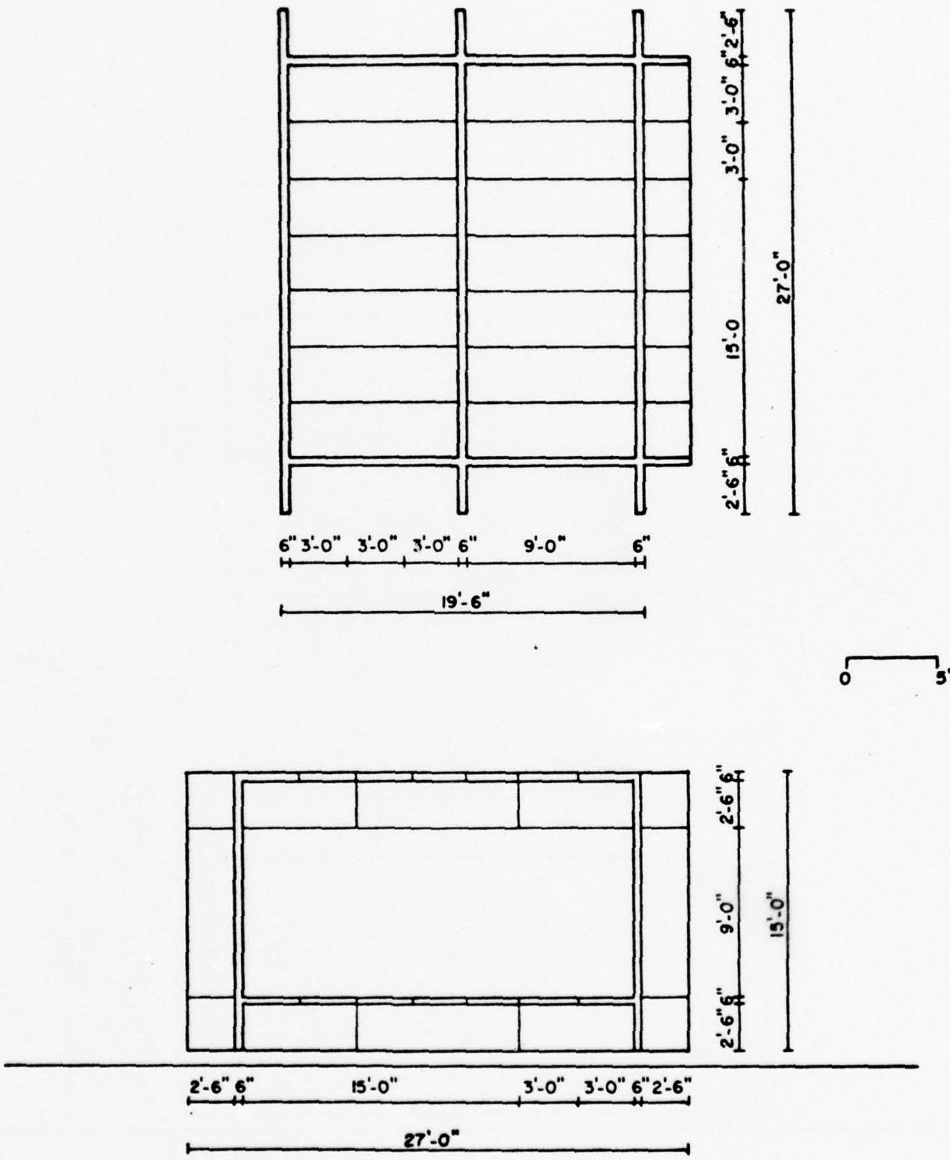

Figure C5. Plan and transverse cross section of 21-ft (6.4-m) wide section, design alternative 2. SI conversion factors: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

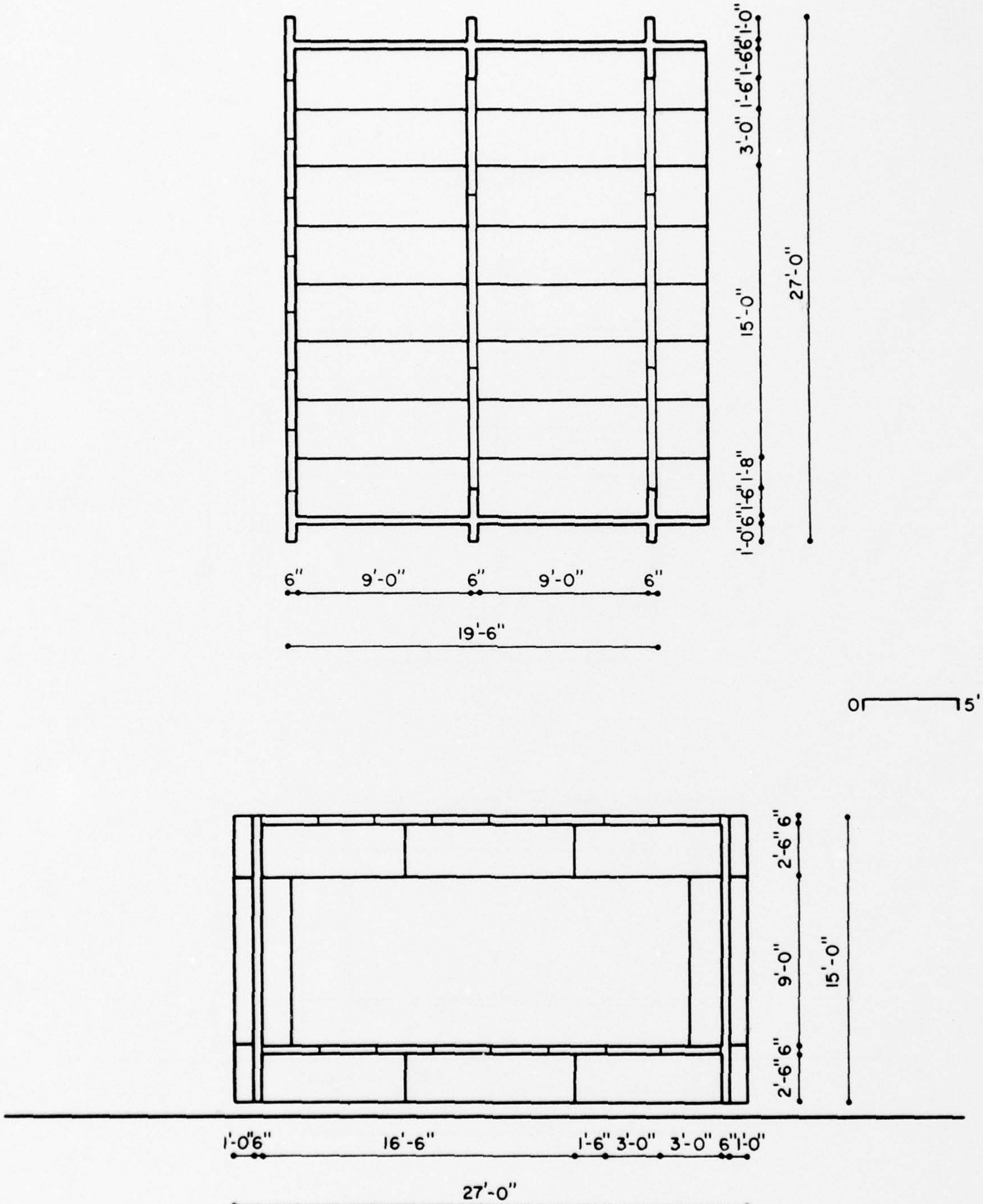

Figure C6. Plan and transverse cross section of 24-ft (7.3-m) wide shelter, design alternative 2A. SI conversion factors: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

columns. This placement, therefore, varied the clear interior dimensions. A typical plan and transverse cross section are given in Figure C7.

5. Design alternative 4 uses a single component with a 4:1 dimensional ratio (3 ft x 12 ft x 6 in. [0.9 m x 3.7 m x 152 mm]). The 3 ft 0 in. (0.9 m) deep panels enable a single panel depth to be sufficient for all spans. Figure C8 gives a typical plan and transverse cross section.

6. Design alternative 5 uses two major components--a steel truss with a 2:1 dimensional ratio panel (5 ft 0 in. x 10 ft 0 in. x 4 in. [1.5 m x 3.0 m x 102 mm]) and a foam-filled metal skin panel (7 ft 2 in. x 10 ft 0 in. x 4 in. [2.2 m x 3.0 m x 102 mm]). Using two different components eliminates over-designing, because each of the two components can be specially designed for a single function. In addition, the light weight of each of the components enables both to be dimensionally large enough to minimize the total number of components as well as the lineal feet of exterior joints. Figure C9 shows typical plans and transverse cross section.

7. Design alternative 5A is similar to alternative 5, except that in 5A, both the steel truss panel and the foam panel are 3 ft 0 in. x 9 ft 0 in. x 4 in. (0.9 m x 2.7 m x 102 mm). This smaller size reduces the weight of the structure considerably while still insuring the structural integrity of the enclosure. Figure C10 presents a typical plan and transverse cross section.

Evaluation of Specific Shelter Alternatives (Step 2B)

A method for determining the design characteristics of each alternative was developed. The method included 26 definitions and a listing of 61 items (25 major data items and 36 subitems) for recording data for comparisons and scoring. Data sheets for each alternative were prepared in accordance with these definitions, which are given in Annex C2. Table C8 is an example data sheet for alternative 1. The evaluation was based on 24-ft (7.3-m) shelter designs. Since some of the data are either constant or insignificant, only 12 data items were used for evaluation. Table C9 gives these 12 data items, including the data for each alternative.

Product/Conclusion - Most Suitable Alternative (Step 2C)

To provide numerical values that could be used to rank the seven alternatives, the alternative demonstrating the most desirable characteristics under a particular heading received a score of seven points, while the least desirable alternative received a score of one

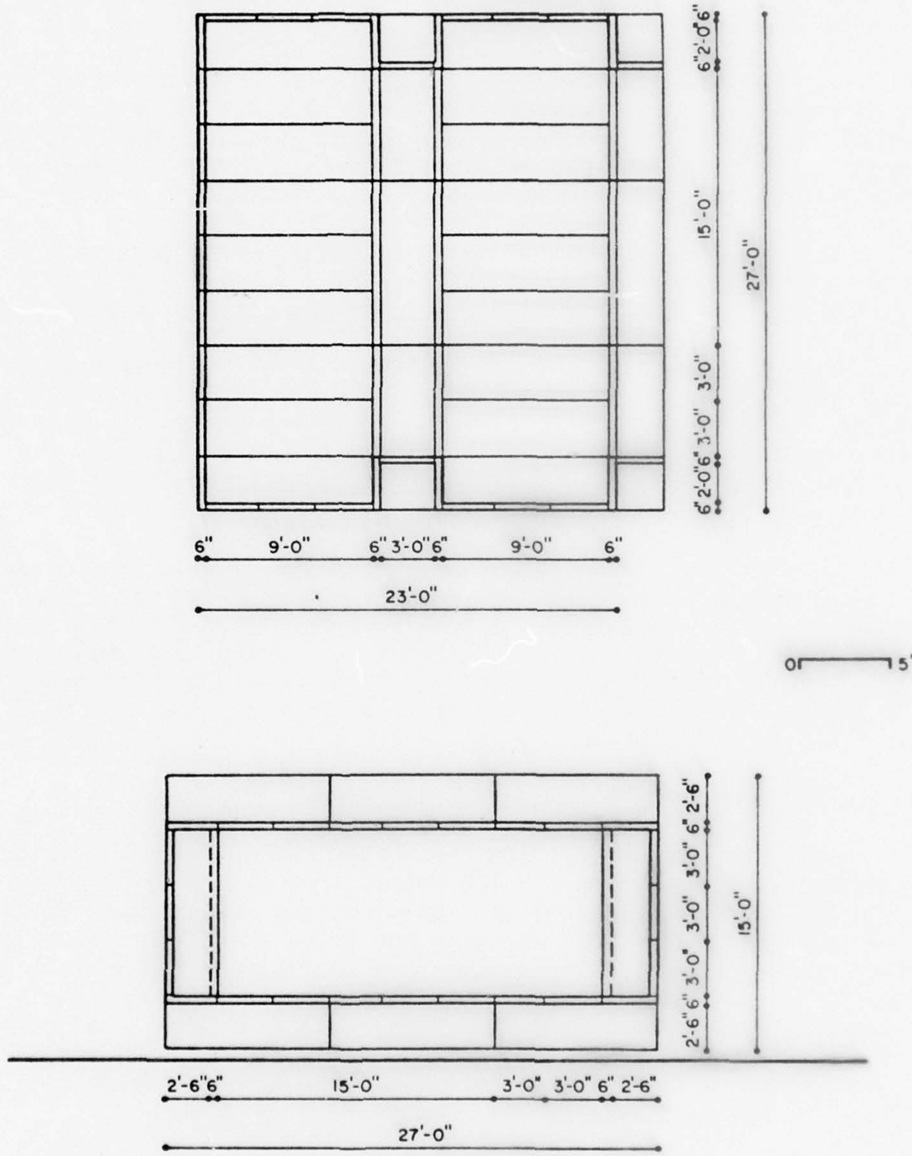

Figure C7. Plan and transverse cross section of 24-ft (7.3-m) wide shelter, design alternative 3. SI conversion factors: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

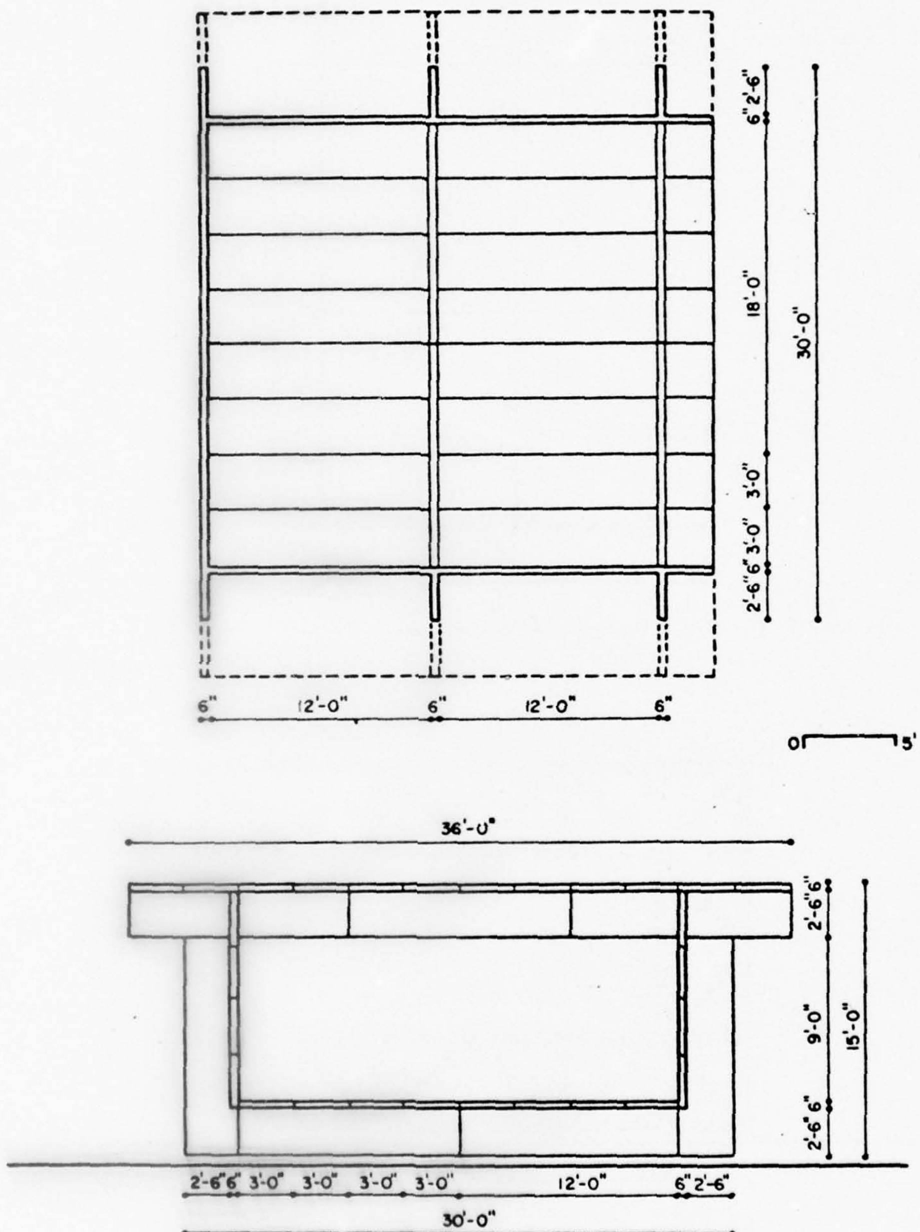

Figure C8. Plan and transverse cross section of 24-ft (7.3-m) wide shelter, design alternative 4. SI conversion factors: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

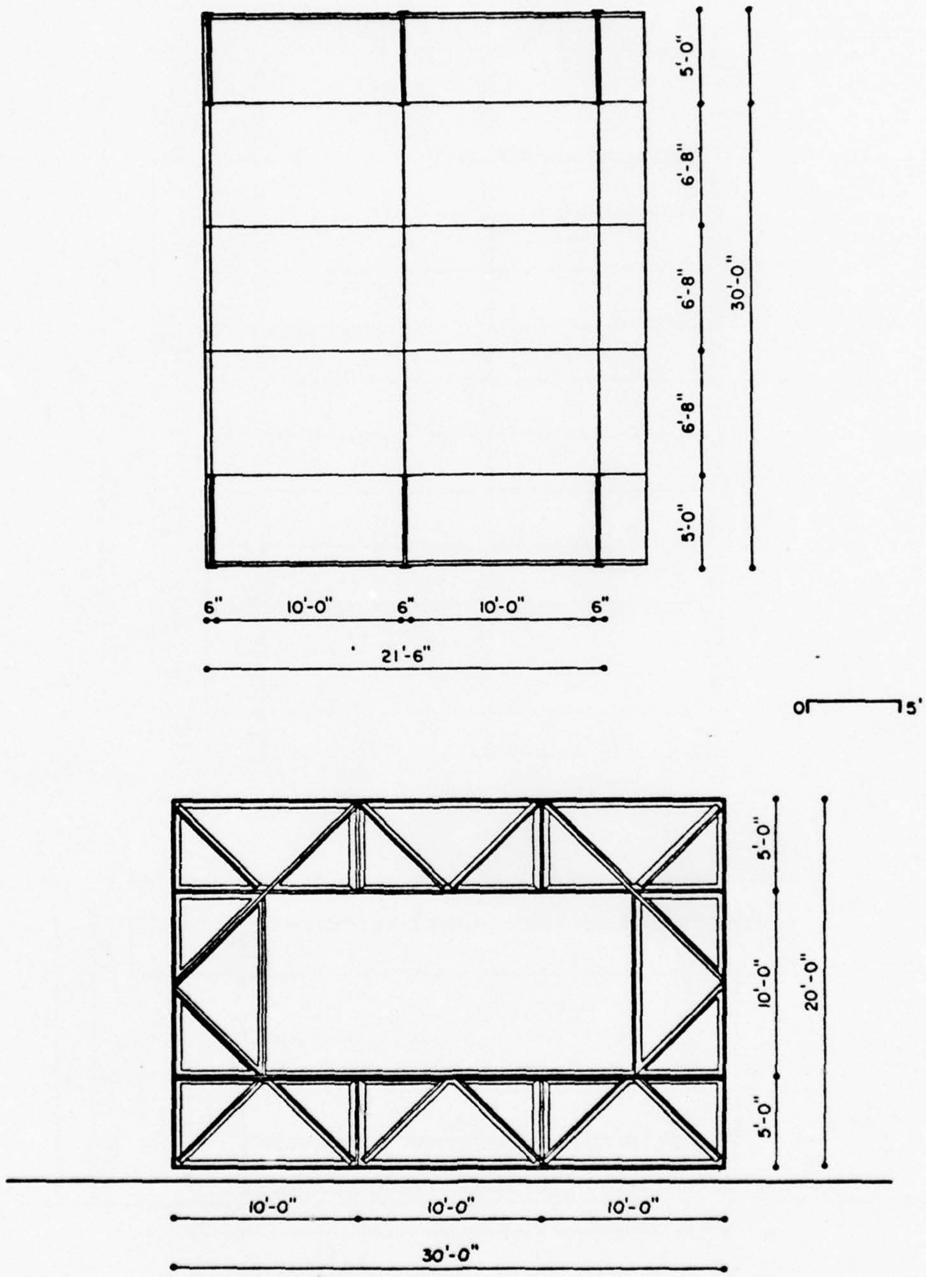

Figure C9. Typical plan and transverse cross section of design alternative 5. SI conversion factors: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

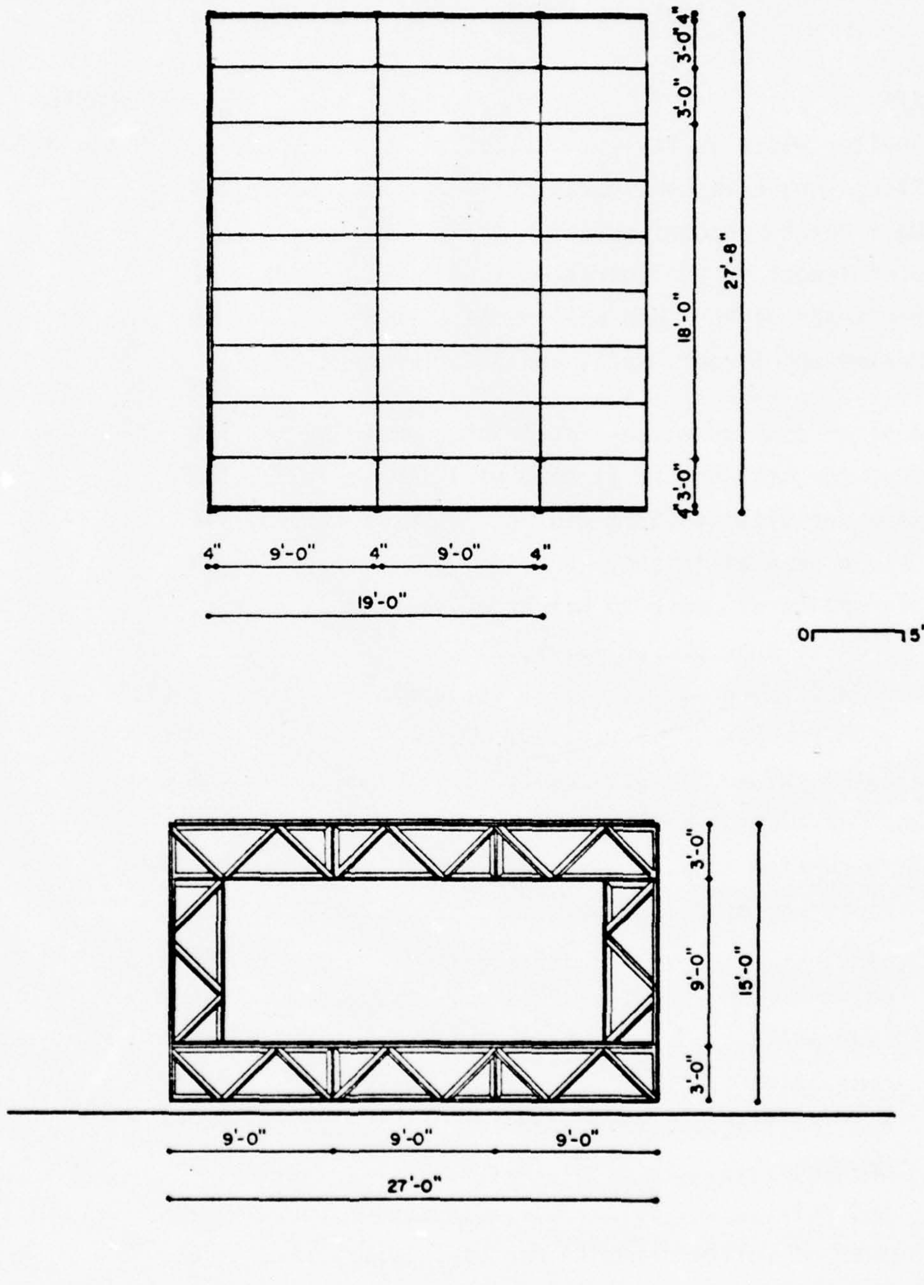

Figure C10. Typical plan and transverse cross section of design alternative 5A. SI conversion factors: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

Table C8

Example Data Sheet (Design Alternative 1)

DATA		REMARKS:
.Shelter width in ft...........................	24	Begin 2:50 PM
.Floor length in configuration in ft...........	24	
.Wall height in configuration in ft............	7.5	
.Roof length in configuration in ft............	24	
.Perimeter of roof and wall members in ft.......	56	
.Perimeter of roof, wall, and floor members in ft..	88	
.Area of configuration--total interior in sq ft.	180	
.Area for standing (8 ft min. ht.), in sq ft....	130	
.Area for sitting (6 ft min. ht.), in sq ft.....	144	
.Usable area efficiency--%.....................	100	
.Proportion of width to height of shelter		
± 12 ft span..................		
± 24 ft span..................2.67:1	2.67:1	
± 48 ft span..................		
.Size of bay in ft.............................	8.0	
.List of element types:		
foundation..................................	Panel	
floor beams.................................	Panel	
floor.......................................	Panel	
columns.....................................	Panel	
side walls..................................	Panel	
roof beams..................................	Panel	
roof/ceiling................................	Panel	
openings....................................	-	
end walls...................................	-	
.Number of unlike elements per bay.............	0	
.Number of elements per type per bay		
foundation..................................	-	
floor beams.................................	4	

Table C8 (cont'd)

floor	12	
columns	2	
side walls	8	
roof beams	4	
roof/ceiling	12	
openings	-	
subtotal	42	
end walls	12	
total	54	Conclude 3:00 PM

SHELTERS/EVALUATION/1

DATA:

.Volume per element and per bay in cu ft	per element	per bay	Begin 3:02 PM
foundation			
floor beams	4	16	
floor	4	14	
columns	4	8	
side walls	4	32	
roof beams	4	16	
roof/ceiling	4	48	
openings			
subtotal	28	168	
end walls	4	48	
total	32	216	

.Carrying size and weight of largest element:

element size.................... panel

element dimensions.............. 3 in. x 2 ft-0 in. x 8 ft 0 in. — 28 high x 2 across x 2 long = 168 panels ÷ 54 panels per bay

element weight in pounds......... 20

.Number of bays to be packed in container — 11 bays, 18 panels

size of container 8 ft x 8 ft x (20 ft-30 ft-40 ft)

(circle appropriate size)

Table C8 (cont'd)

.Number of connections per bay.....	200	4 per panel
.Lineal ft of sealed joints per bay	229	21 x 8 ft = 168 ft + 24 + 88
.Ability to shed water (1 to 5 scale)...........................	2	
.Ease of penetration (1 to 5 scale)...........................	5	
.Ease of construction (1 to 5 scale)...........................	5	$80/panel x 54 panels
.Estimated cost per bay in dollars (materials)......................		200 connections x 1/2 M.H./connection
.Estimated time of assembly per bay in man-hours.....................	100	Conclude: 3:17 PM Total Time: 25 minutes

Table C9

Summary of Data for Each Alternative

	Design Alternatives						
	1	2	2A	3	4	5	5A
Perimeter of roof, wall, and floor member, ft (m)	88 (26.8)	66 (20.1)	71 (21.6)	83 (25.3)	70 (21.3)	75 (22.9)	66 (20.1)
Area efficiency, %	100	70	69.5	70	88	79	75
Size of bay	8 ft 0 in. (2.4 m)	9 ft 6 in. (2.9 m)	9 ft 6 in. (2.9 m)	12 ft 6 in. (3.8 m)	13 ft 0 in. (4.0 m)	10 ft 4 in. (3.1 m)	9 ft 4 in. (2.8 m)
Volume per element and per bay, cu ft (m^3)	64 (1.8) 432 (12.2)	94.5 (2.7) 636.5 (18.0)	94.5 (2.7) 553.5 (15.7)	126 (3.6) 900 (25.5)	94.5 (2.7) 756 (21.4)	120.5(3.4) 641 (18.2)	62.3 (1.8) 382.7 (10.8)
Estimated time of assembly per bay in man-hours	100	52	52	63	103	40	92
Net floor area, sq ft (m^2)	192 (17.8)	228 (21.2)	222 (20.6)	300 (27.9)	286 (26.6)	210 (19.5)	252 (23.4)
Number of connections per bay	200	104	104	126	216	94	184
Number of connections per sq ft (per m^2)	1.04 (11.2)	0.45 (4.8)	0.46 (5.0)	0.42 (4.5)	0.76 (8.2)	0.44 (4.7)	0.73 (7.9)
Linear feet of joint per bay, sq ft	229	249	237	324	348	222	231
Linear feet of joint per sq ft (m per m^2)	1.19 (3.9)	1.09 (3.6)	1.04 (3.4)	1.08 (3.5)	1.37 (4.5)	1.06 (3.5)	0.92 (3.4)
No. of panels per bay	44	32	34	35	48	27	38
No. of panels per sq ft (per m^2)	0.32 (3.4)	0.14 (1.5)	0.15 (1.6)	0.12 (1.3)	0.17 (1.8)	0.13 (1.4)	0.14 (1.5)

point. The points under the various headings were then totaled for each alternative to indicate that alternative's overall performance. Table C10 gives the scores for each alternative under each evaluation item.

All design alternatives presented illustrate the variety of workable solutions which utilize the panel system building concept. Alternatives 1 through 4 use panels as both the structural and enclosure components, while alternatives 5 and 5A use two components -- one for structural component and the other for enclosure component. All of the alternatives have distinct advantages and disadvantages. However, Table C10 shows that design alternative 2 appears to be the most desirable based on the adopted scoring system.

Description of Specific Design Alternative Selected (Step 3A)

Design alternative 2 was selected for further developmental study. Preliminary design calculations performed for the panel unit indicated that it is structurally feasible. Steel and aluminum sandwich panel designs were investigated. Based on the preliminary investigation, steel panel design appears to be less desirable because of weight.

Several methods of weather closure at the joints between panels were investigated. The shelter has five different corner conditions in addition to the straight-line joint segments. Reviewing the methods of closure in relation to the number of joint conditions and splices and the resulting labor and simplicity of application indicated a rank ordering of the closure methods to be liquid, tape, and gasket/cover.

In addition to the basic arrangement shown in Figure C5, other possible types of arrangements were studied. One of the panel system's basic advantages is its flexibility; not only can the individual panels function at any place in the shelter (i.e., floor, column, beam, wall, and roof), but the design alternative can be aggregated in any number of ways. Figures C11 and C12 show two of the possible arrangements.

The disadvantage of the flexibility offered by the system is the redundant structural material necessary in panels not used as structural elements.

Another advantage of this panel system is that the 3-ft (0.9-m) depth enables spanning of distances up to 48 ft (14.6 m). The disadvantage of this approach is that panels are oversized for shorter spans.

Other advantages include flexibility in the placement of openings and interior partitions and ability to aggregate bays to form a variety of building complexes. A further disadvantage is the flat roof configuration, which may present drainage problems.

Table C10

Summary of Scores for Each Alternative

DATA: PART 1

FLAT CONFIGURATION DESIGN ALTERNATIVES	Perimeter of roof, wall, and floor members	Area efficiency (%)	Size of bay	Volume per element and per bay	Estimated time of assembly	Net floor area	Number connections per bay	Number connections per square foot	Linear feet of joint per bay	Linear feet of joint per square foot	Number of panels per bay	Number of panels per square foot	Total
1	2	7	1	6	2	1	1	1	6	1	2	1	31
2	5	4	3.5	4	5.5	4	5.5	5	3	3	6	4.5	53
2A	4	2.5	3.5	5	5.5	3	5.5	4	4	6	5	3	52
3	1	2.5	6	1	4	7	4	7	2	4	4	7	49.5
4	6	6	7	2	1	6	2	2	1	2	1	2	38
5	3	1	5	3	7	2	7	6	7	5	7	6	59
5A	7	5	2	7	3	5	3	3	5	7	3	4.5	54.5

The above chart demonstrates the approach used to compare the seven design alternatives. The judging criteria used were derived from the major headings in the preceding data sheets.

The alternative demonstrating the most desirable characteristics of the seven, in a particular heading, was assigned the highest score of seven points. The alternative with the second most desirable characteristics was assigned a score of six points and so forth. The alternative with the least desirable characteristics under that heading received a score of one point. The points of each alternative under the various headings were then totaled to indicate that alternative's overall performance.

SHELTERS/COMPARISON/24

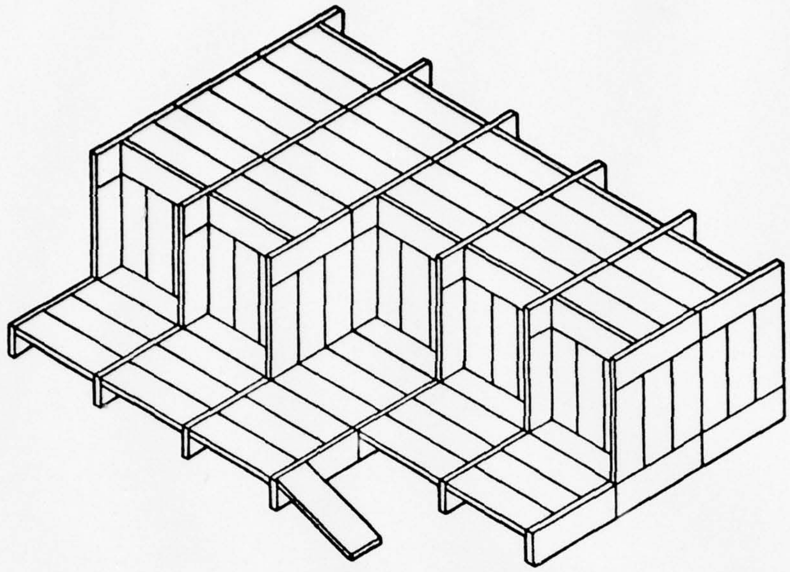

Figure C11. A different arrangement for shelters using 3 ft x 9 ft x 6 in. (0.9 m x 2.7 m x 152 mm) panels.

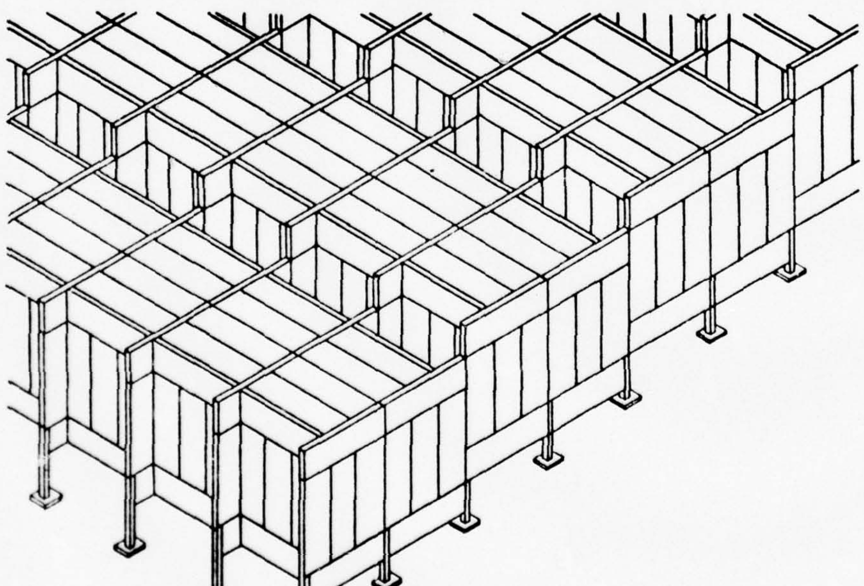

Figure C12. Another different arrangement for shelters using 3 ft x 9 ft x 6 in. (0.9 m x 2.7 m x 152 mm) panels.

Development Plan II

A student design competition was conducted to generate several additional building concepts that meet the same general design guidelines used in Development Plan I. The requirements and format for each submission were prescribed to obtain consistency for evaluation. A total of 10 building alternatives were developed (Figures C13 through C22).

The submissions were evaluated by a reviewing committee consisting of four members each from the University of Illinois Department of Architecture and CERL. The reviewers generally agreed that all submissions were of excellent quality and met the basic criteria stated in the design guidelines. However, three proposals (proposals 3, 6, and 9) that were unique and had great potential for further development were awarded prizes. The reviewing committee's major comments are summarized briefly below.

Proposal 1, although an interesting idea, was thought to be overdesigned.

Proposal 2 was thought to have a very interesting foundation system, especially regarding its capability to adapt to various terrains.

An interesting design was achieved in proposal 3 through the use of the typical panel while achieving light in the space. This solution has some very interesting details and jointing mechanisms.

Proposal 4, utilizing an existing patented building system, applied its concepts in a unique and positive manner. It would, however, appear to have serious reuse problems.

Proposal 5 provides 100 percent spatial efficiency and an interesting structural and skin concept. However, the number of parts and variety of joint conditions may pose problems.

Proposal 6 offers an extremely interesting solution which provides a unique floor and foundation system.

Proposal 7 provides an easily erected system, but the capability of the air-inflated components to insulate, provide security, be repaired, and be flexible in growth was questioned.

Proposal 8 appeared to have too many specialized components. Furthermore, the system's capability to respond easily to the three span requirements was seriously questioned. The construction of the end walls posed another problem, as did the erection process.

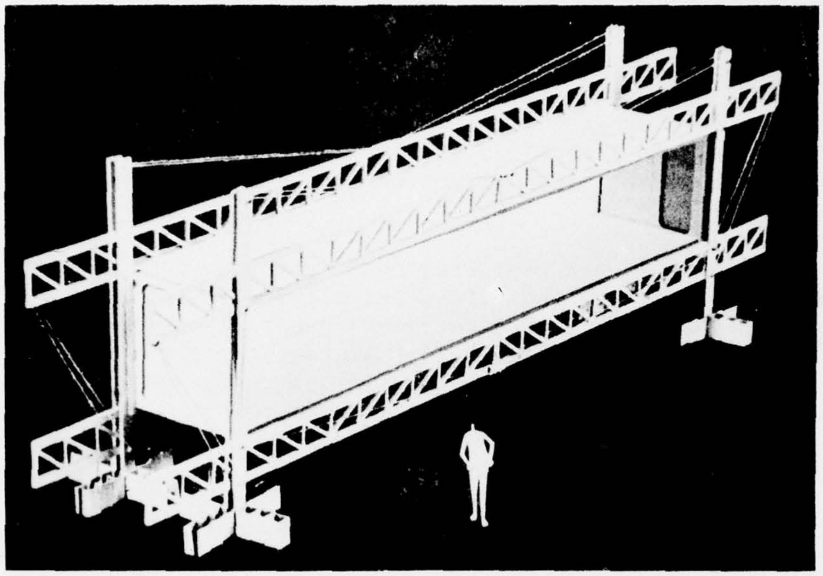

Figure C13. Design concept proposal 1.

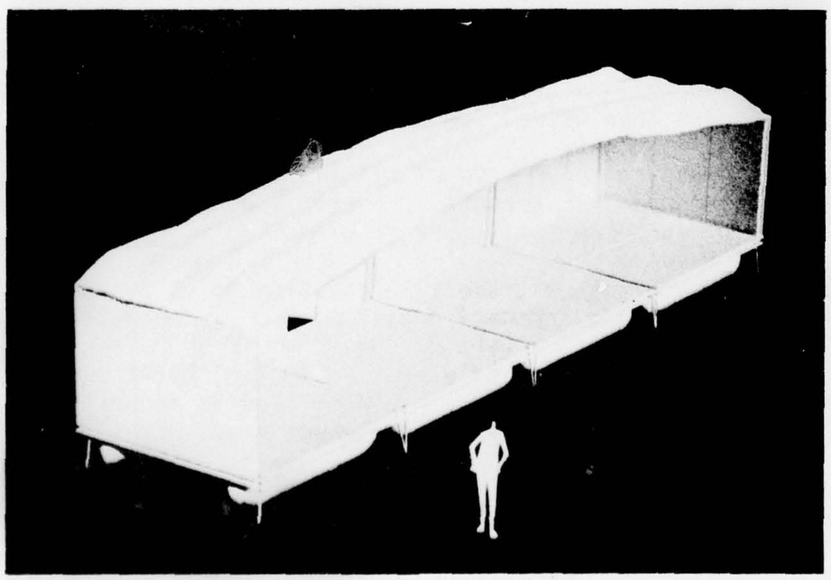

Figure C14. Design concept proposal 2.

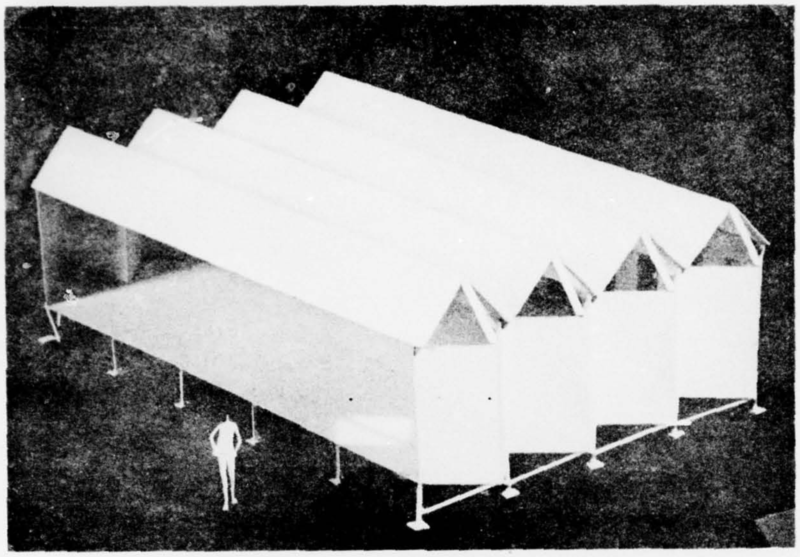

Figure C15. Design concept proposal 3.

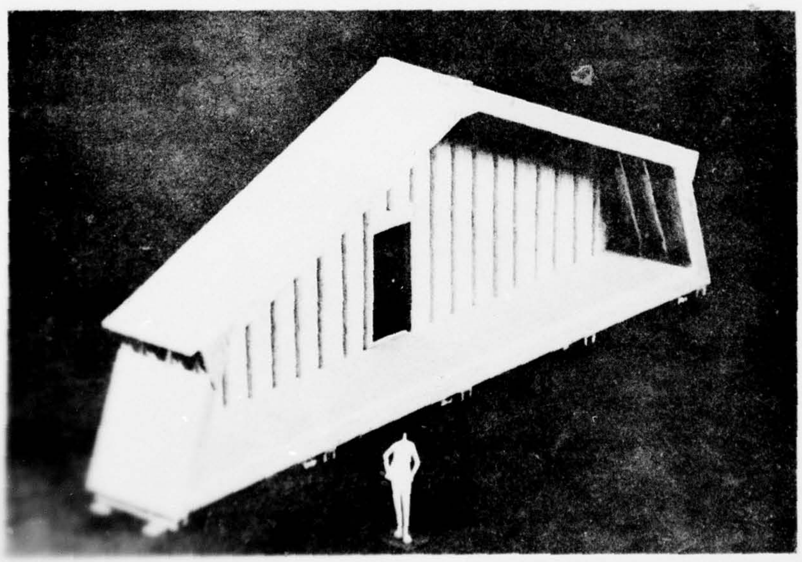

Figure C16. Design concept proposal 4.

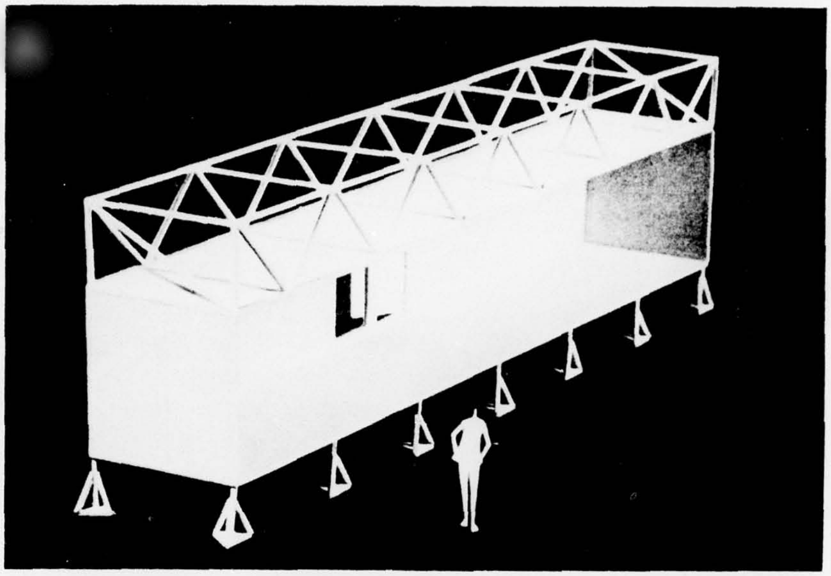

Figure C17. Design concept proposal 5.

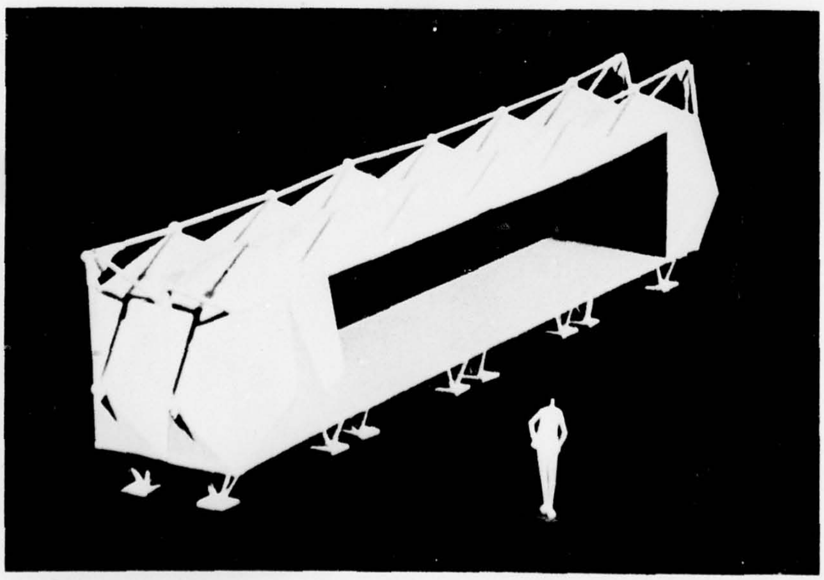

Figure C18. Design concept proposal 6.

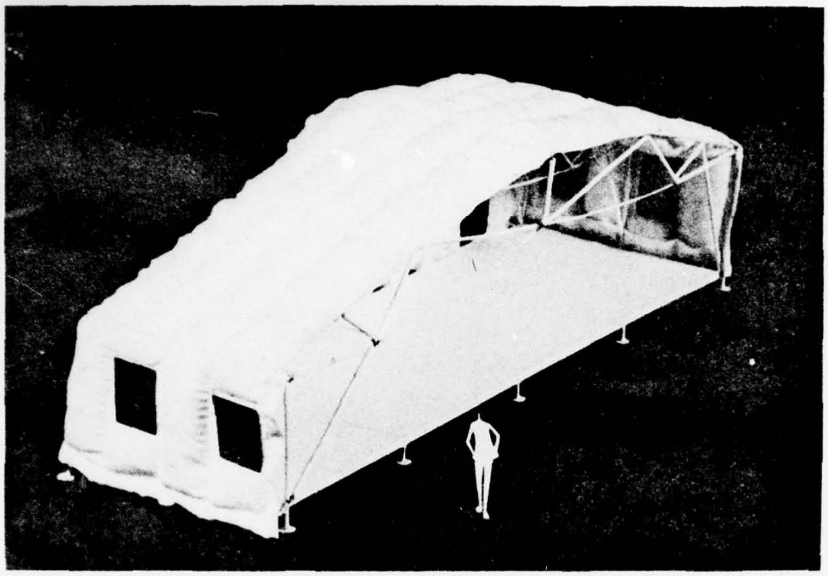

Figure C19. Design concept proposal 7.

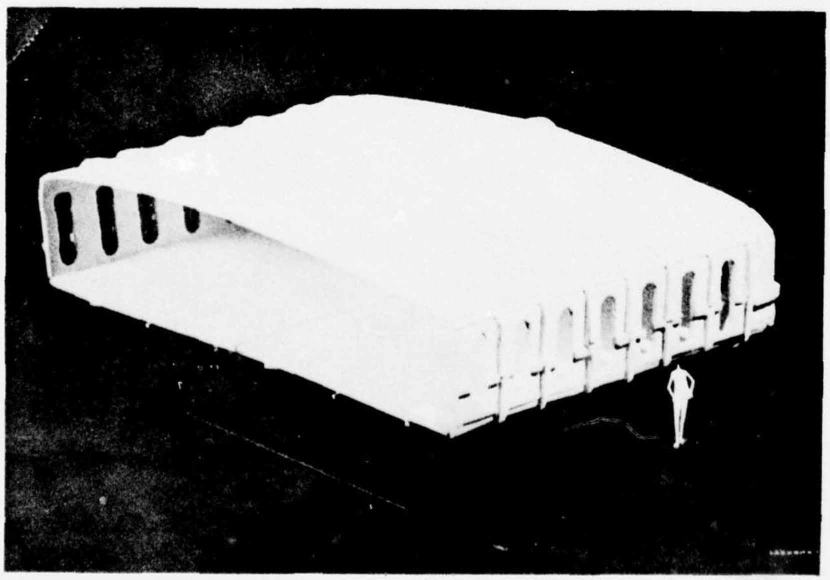

Figure C20. Design concept proposal 8.

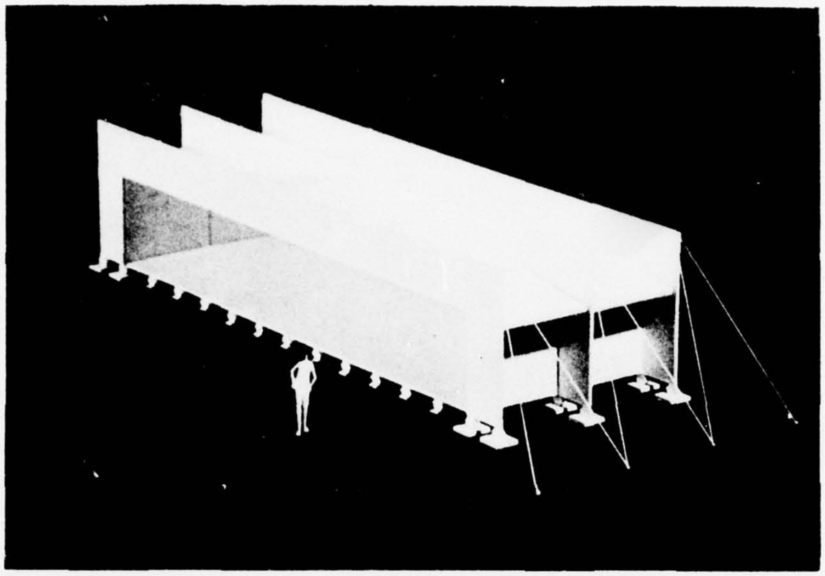

Figure C21. Design concept proposal 9.

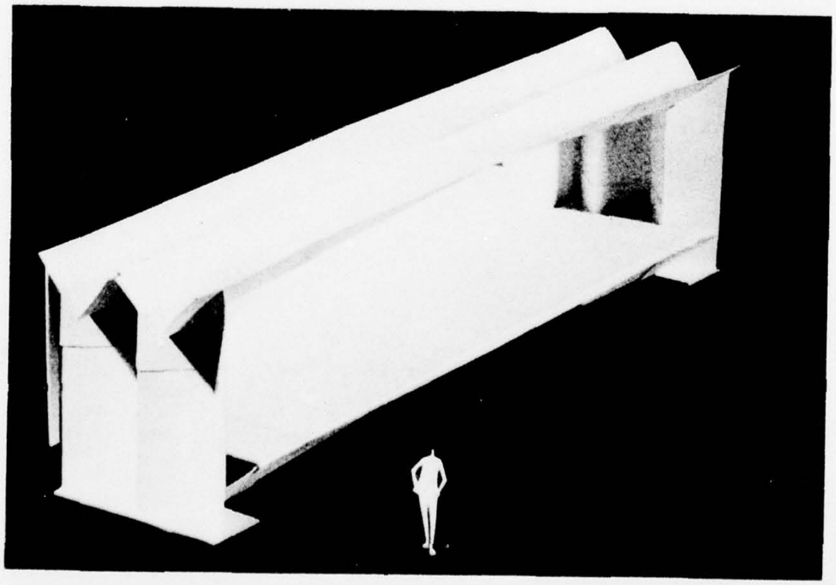

Figure C22. Design concept proposal 10.

Proposal 9 appears to be easily assembled and transported and to minimize the number of elements. It also solved the water run-off problem very well.

Proposal 10 was thought to have an interesting structural concept -- folded plate. However, it was thought that it needed considerable refinement. It also presented some difficult enclosure problems where the walls meet the floor and roof systems.

ANNEX C1:

GENERAL DESIGN GUIDELINES

Purpose of Structures

The purpose of these structures is to provide shelter for a variety of uses in a number of different circumstances. The structures will have application to military, disaster, and low income housing. They should be suitable for use in most temperate zones throughout the world. They may be used for housing, hospitals, storage, offices, and general uses.

Three distinct shelter types are the subject of this project -- a $\pm$ 12-ft (3.7-m) four-man personnel shelter and 24-ft (7.3-m) and 48-ft (14.6-m) general-purpose shelters (all clear span).

Goal of Project

The goal of this project is to achieve the design and development of an "integrated system" that fulfills the general guidelines of this project for the three shelter types.

An "integrated system" is defined as a system using a single element, unit, or component that can be used, when assembled, to form both the structural system and enclosure, i.e., columns, beams, trusses, etc., and roof, ceiling, floor, walls, etc. All connections and joints should be integral with the unit; that is, a part of, rather than separate from it. Doors, windows, vents, etc., should be designed as parts of the system. All components may be exactly the same or the basic component may have variations, i.e., a system of a, a, a, elements . . . or a, a^1, a^2, a^3 . . . In the latter use, the variations should be kept to an absolute minimum.

Use Cycle

The intent of these structures is to provide shelter for that period of time which falls between very temporary shelter for $\pm$ 60 days (i.e., tent) and permanent shelter (i.e., housing built out of masonry, etc.). These structures may need to stay in place up to 18 months. Once permanent housing is built or the area is evacuated, these structures will be disassembled, packaged, and transported to a new site for either storage or assembly for another cycle. The life of these structures or individual parts should be a minimum of 5 years.

Proposal 9 appears to be easily assembled and transported and to minimize the number of elements. It also solved the water run-off problem very well.

Proposal 10 was thought to have an interesting structural concept -- folded plate. However, it was thought that it needed considerable refinement. It also presented some difficult enclosure problems where the walls meet the floor and roof systems.

Easily Erected

The structures must have a method of assembly which is easily understood by unfamiliar and unskilled labor. A minimum of descriptive and instructional material shall be provided for assembly. The structures shall be able to be assembled by labor with hand tools, but the assembly shall not be labor-intensive. It would be desirable to be able to erect a structure within approximately 100 man-hours; i.e., ± 12 hours by eight persons. The variety and number of components in the system should be minimized. (For purposes of design scenario, heavy machinery will not be available for construction, i.e., bulldozers, cranes, etc.) If possible, all size buildings shall be able to be erected from the set of standard components. The basic shelter component should be designed so that it can be handled by a single person (50 lb [22.7 kg]; overhead is the maximum average for a person to lift overhead).

Durability

The system shall require little or no maintenance during its life cycle; damage shall be easily repairable. Repair techniques need not utilize the same material as the original system. Interior and exterior finishes shall be capable of withstanding normal living abuse.

Dimensional Guidelines

Three widths of structures shall be attainable by the system: ± 12-ft (3.7-m) four-man personnel shelters, and ± 24-ft (7.3-m) and ± 48-ft (14.6-m) spans for the general-purpose shelters. (All spans are clear spans.)

The lengths of the structures shall be variable. Additions to the structure shall be easily accomplished. The heights shall be determined by the system's design and shall enclose one story.

Heating and Insulation

The structures shall be designed for use in temperate zones.

Operational Conditions	Five-intmed Hot/Dry	Six-intmed Cold
Ambient air temp., °F (°C)	70 to 110 (21 to 43)	-5 to -25 (-21 to -32)
Solar radiation Btu/sq ft/hr (W/m^2)	0 to 360 (0 to 1135.7)	negligible
Ambient relative humidity, %	20 to 85	tending toward saturation
Storage and Transit Conditions		
Induced air temp., °F (°C)	20 to 145 (-7 to 63)	-10 to -30 (-23 to -34)
Induced relative humidity, %	5 to 50	tending toward saturation

Heating of the shelters shall be accomplished by simple unit space heaters. Ventilation will be required. Insulation shall be at least the equivalent of a normal house.

Ventilation and Daylight

The system shall be designed to enable penetration into the structure for access, ventilation, and daylight. As a guideline, normal code standards shall be assumed:

For ventilation: five percent of room area

For daylight: 10 percent of room area.

Foundations

The foundations must be as simple as possible, yet perform as required. The number of foundations should be minimized. Foundation design shall be able to adapt to varying ground conditions as the terrain may vary in materials, slope, etc. The site preparation requirements shall be at an absolute minimum.

Joints

Joints in the exterior skin should be minimized and weather-proofed where necessary against snow, rain, and wind.

Weight

Although no exact criteria are specified, the total weight of each structure shall be low as is feasible in order to cut down shipping weight. In addition, the weight of the system's components shall be no more than what two to four men can lift. One or two men should be able to lift and carry most components.

Skin

The exterior skin must be durable and easily applied if not an integral part of structure.

Costs

The cost of materials for the shelter shall be minimized. An approximate maximum shall be \$10/sq ft (\$107/m^2). As a point of comparison and competition, a wood structure was recently built for \$5.50/sq ft (\$59.20/m^2) (inflation may have increased that figure). The cost figure must reflect the typical mass-produced unit, not an initial tooling-up cost.

Transportable

The system shall be designed in such a way that it can be transported in typical containers: 8 ft x 8 ft (2.4 m x 2.4 m), 20, 30, or 40 ft (6.1, 9.1, or 12.2 m) long. The 20-ft (6.1-m) box is preferred. (For inside dimensions, subtract 6 in. (152 mm) from the above dimensions.) The components shall be able to be easily loaded, packed, and transported. The components shall be designed to minimize the transporting of "air," i.e., empty space. The number of components in one container, whether in a knocked down or assembled state, should be maximized, as should the number of structures in one container.

Use of Shelters

Housing (individual and group)

Toilets

Dining

Store

Hospitals

Offices

Activities

Sleeping

Sitting-Relaxation

Eating

Food Preparation

Storage

Toilet-Hygiene

Typing

Filing

Conference

ANNEX C2:

DEFINITIONS OF BUILDING TERMS

Shelter Width: The approximate span dimension i.e., 12 ft (3.7 m), 24 ft (7.3 m), or 48 ft (14.6 m).

Floor Length in Configuration: The exact *interior* dimension in cross section.

Wall Height in Configuration: The exact *interior* dimension in cross section where applicable.

Roof Length in Configuration: The exact *interior* dimension in cross section.

Perimeter of Roof and Wall Members: The exact *exterior* dimension in cross section.

Perimeter of Roof, Wall, and Floor Members: The exact *exterior* dimension in cross section.

Area of Configuration--Total Interior: The area of the interior space indicated in the cross section.

Area for Standing (8 ft [2.4 m] min. ht.): The cross-sectional area described by the floor and a line 8 ft (2.4 m) above the floor to the interior surface of both walls.

Area for Sitting (6 ft [1.8 m] min. ht.): The cross-sectional area described by the floor and a line 6 ft (1.8 m) above the floor to the interior surface of both walls.

Usable Area Efficiency--%: The ratio of the area for standing to the total interior area of configuration.

Proportion of Width to Height: The ratio of width to height with the height equated to 1., i.e., 4.2.:1.

Size of Bay: The dimension of the basic structural unit of growth for the building--i.e., column to column.

List of Element Types: The various types of elements for each of the building components (foundation, floor beams, etc.) i.e., floor beam . . . structural steel WF or panel or inflated tube or, side walls . . . metal sandwich panel, or plywood panel or inflated membrane.

Number of Unlike Elements per Bay: The number of different elements in a typical bay; i.e., structural steel WF and panel are two unlike elements. If there are elements of the same type which have differing sizes, these qualify as "unlike elements," i.e., two structural steel members of the same cross section but of differing lengths, or two of the same length but different cross sections.

Number of Elements per Type per Bay: The total number of elements in a bay for one element type, i.e., floor beams . . . four (structural steel sections).

Volume per Element and per Bay: The approximate product in cubic feet for each element multiplied by the number of elements in each bay, i.e., floor . . . (panels 6 in. x 3 ft x 12 ft) = 18 cu ft x 10 panels/bay = 180 cu ft (152 mm x 0.9 m x 3.7 m) = 0.5/m^3 x 10 panels/bay = 5.1 m^3).

Weight per Element and per Bay: Approximate weight of the element based on the volume, i.e., floor--(concrete panels--18 cu ft x 50 lbs/cu ft) = 900 lb/panel and 9000 lb/bay (0.5 m^3 x 800.9 kg/m^3 = 400.45 kg/panel and 4004.5 kg/bay). (Figures for weights can be found in various references--"graphic standards," structural handbooks, etc.)

Carrying Size and Weight of Largest Element: The largest element based on the above calcaulations. If the largest element in dimension is not the heaviest, record both elements.

Number of Bays to Be Packed in Container: The number of bays which can be placed in the container. Indicate the size of the container.

Number of Connections per Bay: The number of points in the system where actual connections of elements to elements are made. Figure does not necessarily indicate the number of bolts; if, for example, a panel needs to be connected to some other element at the four corners with 20 bolts, the number of connection points totals four.

Linear Feet of Sealed Joints per Bay: Total lineal feet of joints which must be sealed against the weather with sealant, a gasket, or the like.

Ability to Shed Water: Estimate of the shelter's ability to shed water on a scale of one to five (five is excellent).

Ease of Penetration: Estimate (on a scale of one to five) of the ease of penetrating the enclosure for doorways, windows, ventilation, etc. Take into consideration whether the method of penetration is an integral part of the system.

Ease of Construction: Estimate (on a scale of one to five) of the system's ease of construction based on the guidelines discussed in the general design guidelines.

Estimated Cost per Bay (Materials): Approximate cost of materials per bay. Use the means cost estimating guide.[6] For example, metal panels are approximately \$5.15 sq ft (\$55.43/m^2). Therefore, 10 panels at 10 sq ft/panel = \$515.00/bay plus the cost of other elements. This is not to be a detailed estimate.

Estimated Time of Assembly per Bay (Man-Hours): Approximate time of assembly, recognizing the process of building. Do not include unloading the container. For example, if you have 10 panels with four points of connection estimated to require 15 minutes per connection by two persons, the time to assemble one bay of 10 panels is 20 man-hours.

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[6] *Building Construction Cost Data* (Robert Snow Means Co., annual editions).

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